Financial Analysis of Restoring Sustainable Forests on Appalachian Mined Lands for Wood Products, Renewable Energy, Carbon Sequestration, and Other Ecosystem Services

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Keywords: financial feasibility, economic analysis, land expectation value, incentive schemes, value of carbon, land-use conversion, surface mined land reclamation

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ABSTRACT

Public Law 95-87, the Surface Mining Control and Reclamation Act of 1977 (SMCRA), mandates that mined land be reclaimed in a fashion that renders the land at least as productive after mining as it was before mining. In the central Appalachian region, where prime farmland and economic development opportunities for mined land are scarce, the most practical land use choices are hayland/pasture, wildlife habitat, or forest land. Since 1977, the majority of mined land has been reclaimed as hayland/pasture or wildlife habitat, which is less expensive to reclaim than forest land, since there are no tree planting costs. As a result, there are now hundreds of thousands of hectares of grasslands and scrublands in various stages of natural succession located throughout otherwise forested mountains in the U.S. The purpose of this study is to develop a framework for understanding/calculating the economic implications of converting these reclaimed mined lands to forests under various silvicultural regimes, and to demonstrate the economic/decision-making implications of an incentive scheme on such a land use conversion. The economic feasibility of a range of land-use conversion scenarios was analyzed for both mixed hardwoods and white pine, under a set of low product prices and under a set of high product prices. Economic feasibility was based on land expectation values. Further, three types of incentive schemes were investigated: 1) lump sum payment at planting (and equivalent series of annual payments), 2) revenue incentive at harvest and 3) payment based on carbon volume.

Mixed hardwood LEVs ranged from -$2416.71/ha (low prices) to $3955.72/ha (high prices). White pine LEVs ranged from -$2330.43/ha (low prices) to $3746.65/ha (high prices). A greater percentage of white pine scenarios yielded economically feasible land-use conversions than did the mixed hardwood scenarios, and it seems that a conversion to white pine forests would, for the most part, be the more appealing option. It seems that, for both mixed hardwoods and white pine, it would be in the best interests of the landowner to invest in the highest quality sites first. For a conversion to mixed hardwood forests, a low intensity level of site preparation seems economically optimal for most scenarios. For a conversion to white pine forests, a medium intensity level of site preparation seems economically optimal for most scenarios.

Mixed hardwoods lump sum payments, made at the time of planting, ranged from $0/ha to $2416.71/ha (low prices). White pine lump sum payments, made at the time of planting, ranged from $0/ha to $2330.53/ha (low prices). Mixed hardwoods benefits based on an increase in revenue at harvest, ranged from $0/ha to $784449.52/ha (low prices). White pine benefits based on an increase in revenue at harvest ranged from $0/ha to $7011.48/ha (high prices). Annual mixed hardwood benefits, based on total stand carbon volume present at the end of a given year, ranged from $0/ton of carbon to $5.26/ton carbon (low prices). White pine benefits based on carbon volume ranged from $0/ton of carbon to $18.61/ton of carbon (high prices). It appears that, for white pine scenarios, there is not much difference between incentive values for lump sum payments at planting, revenue incentives at harvest, and total carbon payments over a rotation. For mixed hardwoods, however, it appears that the carbon payment incentive is by far the cheapest option of encouraging landowners to convert land.

Keywords: financial feasibility, economic analysis, land expectation value, incentive schemes, value of carbon, land-use conversion, surface mined land reclamation

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CHAPTER I – INTRODUCTION AND OBJECTIVES

I.1. Introduction

Public Law 95-87, the Surface Mining Control and Reclamation Act of 1977 (SMCRA), has drastically altered surface mining and reclamation practices. The intent of this law is to ensure that surface mined land is reclaimed to a condition capable of supporting a productive land use. Therefore, coal companies are required to specify a post-mining land use for which the land will be reclaimed. Furthermore, productivity standards were established for various land uses, and coal companies are required to post a performance bond that will only be returned if the performance criteria for the specified land uses are achieved within five years. In the central Appalachian region, where prime farmland and economic development opportunities for mined land are scarce, the most practical land use choices are hayland/pasture, wildlife habitat, or forest land. Since 1977, the majority of mined land has been reclaimed as hayland/pasture or wildlife habitat, which is less expensive to reclaim than forest land, since there are no tree planting costs. Although an accurate measure of the total area converted from forests to grasslands is not available, an estimated 614000 hectares in the eastern U.S. alone has been mined between 1978 and 1997, and has achieved bond release, with the majority of this land being reclaimed to grasslands (OSM, 2000). Such post-mining land uses may be useful and economically feasible on lands mined by mountain top removal methods, if these lands will indeed be used for grazing, or growing and harvesting hay. However, in reality, lands with steep slopes that are mined by contour mining methods and reclaimed as hayland and pasture land are not ideally suited for grazing or harvesting hay, primarily due to limited accessibility by machinery and animals. Therefore, in most instances, these lands are abandoned following bond release, and slowly revert back to relatively unproductive stands of understocked and undesirable tree species. Perhaps this is why the general perception of land disturbed by strip-mining for coal has historically been one of devastated, unproductive wasteland (Plass & Burton, 1967).

According to SMCRA requirements, mine operators are responsible for reclaiming mined land. Thus, landowners tend to defer post-mining land-use decisions to the coal operator. The major problem with this setup is the lack of long-term interest that the coal operators have in the land. Thus, these coal operators attempt to reclaim the land in (what they perceive to be) the cheapest and least time-consuming way possible. As a result, there are now hundreds of thousands of hectares of grasslands and scrublands in various stages of natural succession located throughout otherwise forested mountains. Most of these lands will eventually become forests by default via natural succession. However, because of existing soil and vegetation properties created by inadequate reclamation, this process will require as much as several hundred years, and the forests' potential to produce timber and to sequester carbon will remain poor due to the poor soil physical and chemical properties created during mine reclamation (Burger et al., 1999). From a purely economic standpoint, this time delay equals money lost. Hence, the question must be posed: why wait several hundred years, using grasses to reclaim mined lands, to reap the economic and ecological equivalent benefits of a mature forest, when the same results could possibly be achieved in a fraction of that time, through afforestation?

Public Law 95-87 mandates that mined land be reclaimed in a fashion that renders the land at least as productive after mining as it was before mining (Torbert et al., 1995).

Research has shown that restored forests on mined lands can be equally or more productive than the native forests removed by mining (Burger and Zipper, 2002). Given that most land surface-mined for coal in the Appalachians was originally forested, it would appear that forestry is a logical land-use for most of the reclaimed mined land in the Appalachian Mountains (Torbert and Burger, 1990). However, since implementation of the SMCRA, it appears that fewer forests are being restored (Burger et al., 1998). At the same time, planting of tree seedlings is in fact one of the most commonly used methods of revegetating spoil bank areas in some states (Brown 1962), such as Virginia, where (since 1991) 86% of Virginia's mined land has been reclaimed to forested post-mining land uses. Unfortunately, the majority of mined land reclaimed as forest land is not reclaimed in a way that favors tree establishment, timber production, carbon sequestration, and (more importantly) long-term forest productivity (Torbert and Burger, 1990).

It is believed that these reclaimed mined lands are producing timber and sequestering carbon at rates far below their potential for reasons that include poor mine soil quality, inadequate stocking of trees, lack of reforestation incentives, and regulatory disincentives for planting trees on previously forested land (Boyce, 1999; Burger and Maxey, 1998). A number of these problems can be ameliorated simply through intensive silvicultural management. Through established site preparation techniques such as ripping, weed control, fertilizing and liming, the quality of a given site can be improved considerably. Other management and silvicultural techniques such as site-species matching, correct planting techniques, employing optimal planting densities, post-planting weed control, and thinning can also go a long way to ensuring improved development of forest stands, and subsequently improved timber production and carbon sequestration.

Similar to the much-debated topic of converting agricultural land to forests, the conversion of reclaimed mined lands to forests carries with it many economic implications. The primary difference between converting agricultural lands to forests, and converting reclaimed mined lands to forests is the absence of any obvious extrinsic opportunity cost in the latter scenario; this, of course, only under the assumption that the reclaimed mined land has been abandoned, and is not being utilized for any economically beneficial purpose.

A fair amount of research has been conducted regarding the amounts and values of timber produced on reclaimed mined lands. The effect that a carbon market may have on decisions pertaining to the reclamation of mined lands has also been researched. According to previous research, it appears that mined lands are capable of sequestering carbon and producing harvest volumes of equal or greater magnitude to similar non-mined lands. This fact alone, however, does not render afforestation of mined lands economically profitable or feasible in all cases. There appears, at this stage, to be a lack of research pertaining specifically to the conversion of reclaimed mined lands from their current use to forests, and the economic implications of such a land use conversion. Furthermore, the potential for an incentive scheme aimed at promoting the conversion of reclaimed mined lands to forests has yet to be explored in depth.

This study ultimately addresses the potential for increasing carbon sequestration on surface-mined land. The overall research objective of this study is to *determine the economic feasibility of carbon sequestration through converting reclaimed mined lands* *to forests using high-value tree species, and to demonstrate the economic/decision-making implications of an incentive scheme on such a land use conversion.*

I.2. Objectives

The specific objectives of this study are the following:

1. Develop a framework for calculating/understanding:
    - the economic implications of converting reclaimed mined lands to forests under various: silvicultural regimes, alternative rates of return and timber prices.
    - incentive schemes required to render regimes profitable for landowners.
2. Evaluate the economic feasibility of converting mined land, reclaimed since the implementation of SMCRA in 1978, from grasslands to high-quality white pine and mixed hardwood forests through the:
    - estimation of market benefits and costs of conversion, for various silvicultural regimes , alternative rates of return and timber prices.
    - estimation of the present value of net benefits for the private landowner that follow from market activities over a range of scenarios (by varying: site preparation costs, timber prices and alternative rate of return).
3. Calculate incentive levels required to render regimes profitable for landowners. This will entail the evaluation of three different incentive schemes:
    - Lump sum payment, paid at the time of planting – this payment will equate to a once-off payment made at the time of planting, in order to render the given

scenario economically feasible. This payment, paid at the time of planting, will also be translated into an annual payment.

- Payment based on revenue received at harvest – this payment will equate to the increase in revenue at harvest required to render the given regime economically feasible.
- Payment based on carbon volume – this payment will equate to an annual payment per unit carbon volume, required to render the given scenario economically feasible. In other words, we will calculate the value of carbon necessary to render a given scenario economically feasible.

CHAPTER II – LITERATURE REVIEW

II.1. Introduction

Literature pertaining to the reclamation of mines in general is in abundance. Much of the literature describes mine reclamation techniques, and the advantages and disadvantages of mine reclamation. Relatively few studies have been conducted researching the economic feasibility of mine reclamation through forestry. This literature review is divided into four primary subsections: 1) economic analyses, 2) taxes, subsidies and policy design, 3) survival rates of planted trees and 4) growth and yield on reclaimed mined lands. In reviewing the literature on mine reclamation and carbon sequestration, I focused primarily on studies that dealt with mining-, carbon sequestration- and forestry-related economic analyses. Secondly, I reviewed studies that dealt with taxes and subsidy design. Lastly, in order to obtain data for use and comparison in my study, I reviewed studies that dealt with the survival rates of planted hardwood and pine plantation trees, and the growth and yield of various tree species on reclaimed mined lands.

II.2. Economic analyses

The financial feasibility of converting reclaimed mined lands to forests is not well-researched. In fact, only one such study was found. However, the concept of, and methods used in, analyzing the financial feasibility of a land-use conversion is by no means unique to reclaimed mined lands. Therefore, the search for literature was extended to a variety of forestry-related economic studies, with a concentration on carbon sequestration-related studies.

II.2.1. Mined land study

Kronrad et al. (2002) conducted an economic feasibility study on abandoned mine lands in Pennsylvania, Ohio, West Virginia, Kentucky, Tennessee, Virginia, Maryland and North Carolina. The purpose of this study was to 1) calculate the profitability of planting and managing forests on abandoned mine lands for the dual products of timber and carbon storage, 2) calculate the total amount of carbon that can be stored, and 3) determine the average cost of sequestering carbon. They considered only pure red oak (*Quercus rubra*) stands in their study. Variables used in the study include a range of site indices, rates of return, costs of site preparation, and values for each ton of carbon stored. Five site indices, 40, 50, 69, 70 and 80 (base age 50), were used and six alternative rates of return (ARR), 3.5, 5.5, 7.5, 10, 12.5, and 15% were considered. Site preparation costs ranged from $300/acre (low site preparation cost) to $1325/acre (high site preparation cost), and sawtimber and pulpwood prices were adjusted according to the state. Five thinning intensities were employed: 20, 25, 30, 35 or 40% of basal area removal. For their analyses, the price of carbon was assumed to be $10, $50, or $100 for each additional ton of carbon that is sequestered. They evaluated several thinning and harvesting schedules in order to determine optimal thinning and harvesting schedules. For this part of the study, the Forest Vegetation Simulator (FVS) was used to simulate growth and yield of red oak in the Appalachian region. For each thinning and harvesting schedule combination, economic analyses were performed to determine net present value and soil expectation value. Results were then used to determine how profitable red oak management is on abandoned mine land, how profitable it is to sell timber and carbon credits on these sites, how much carbon can be stored on an acre of abandoned mine land,

and the cost of sequestering carbon on these lands. The results of Kronrad et al.'s study suggest that as site quality increases and real rate of return decreases, the average cost of sequestering carbon decreases. The profitability of forest management increases as the assumed market price of carbon increases. Hence, as soil quality increases, profitability increases, but as the rate of return increases, forest investment becomes less appealing. They conclude by suggesting that investments should be made on the highest quality sites first and in projects that require the lowest site preparation costs.

II.2.2. Carbon economics studies

Ravindranath and Somashekhar (1995) conducted a study to analyze the potential and economics of various forestry options for carbon sequestration in India. Although not on mined lands, one of these options was the revegetation of degraded lands, under various management regimes. The "Soft Wood Forestry" (SFW) option (6 year rotation) yielded a NPV of $122/ha at a commercial interest rate of 12%, and a NPV of -$226/ha at an interest rate of 17.25%. The "Timber Forestry" (TF) option (hardwoods – rotation length not specified) yielded a NPV of $67 at an interest rate of 12% and a NPV of -$186 at an interest rate of 17.25% (1994 prices and exchange rate). Benefits considered included the value of biomass extracted per hectare of different options, namely: firewood, timber and some non-timber products. Establishment costs comprised expenditures in the initial 2 or 3 years for the establishment of the tree plantations. Ravindranath and Somashekhar report carbon sequestration rates of 80 tonnes/ha and 120 tonnes/ha for the SFW and TF options respectively. The NPV/tonne of carbon sequestered were reported as $1.5 and $0.5 for the SFW and TF options, respectively.

The sequestered carbon values are net values after deducting the carbon emissions from clearfelling and end use. According to Ravindranath and Somashekhar, the two major sources of carbon emissions in India are energy and forestry. They report that the investment cost per tonne of carbon benefit is lower for all forestry options compared to energy options.

In a study similar to that of Ravindranath and Somashekhar, Ismail (1995) evaluates the economics of various forestry options in Malaysia that contribute to the reduction of carbon dioxide in the atmosphere. Three types of forest management regimes are examined: (1) protective forestry, (2) production forestry and (3) plantation forestry. Ismail uses three criteria to evaluate the effectiveness in carbon sequestration: (i) Net Present Value (NPV) – derived from cash flow (discount rate = 8%), (ii) – Net Present Value of Carbon (NPVC) – derived from carbon flow table using discount rates of 0%, 1% and 3%, and (iii) Benefit of Reducing Atmospheric Carbon (CRAC) – ratio of NPV divided by NPVC, multiplied by the sum of the discount rate and decay rate of atmospheric carbon. The role of protective forests is simply to sequester carbon dioxide until the climax stage where the net carbon sequestered is zero. Due to the loss in potential timber revenue, this management regime yielded negative NPVs for all variations. The production forest management regime is aimed at a sustainable supply of timber through selective logging. Results indicate that the production forests returned a relatively higher NPV compared to the protective forests, primarily due to revenue generated from old growth (virgin) forests. The plantation option yielded between 5 and 50 times the carbon sequestering capacity over the productive and protective forests. Results for plantation forests are presented in Table 1.

Table 1 – Carbon flow analysis for plantation forest areas (Ismail, 1995)

	CRAC	NPVC ($/ha)	NPV ($/ha)
Quality timber (30 yrs)			
0%	0.12	300.3	-410
1%	0.16	230.175	-410
3%	0.25	146.675	-410
Fast growing species (3 x 10 yrs)			
0%	-2.68	585.9	17455
1%	-3.31	475	17455
3%	-4.73	332.225	17455

The negative NPVs for quality timber management are attributed to the long rotation, and high initial establishment costs incurred. Ismail concludes that, although forest plantations could sequester the highest amounts of carbon per unit area, natural forests which are managed for sustainable timber production are the cheapest option for per-unit area carbon sequestered.

Xu (1995) calculated the amount of carbon sequestered through large-scale afforestation in China, and calculated related costs and benefits, assuming that the forests are managed in perpetual rotations. Similar to the carbon sequestration rates reported by Ravindranath and Somashekhar (1995), amounts of carbon sequestered varied, over a range of management scenarios, between 6.3 tons/ha and 146.4 tons/ha. NPVs calculated for the various management regimes ranged between -$39.80/ha and $1176.95/ha. Xu concludes that, given the results of this study, the least expensive way of developing forests for the purpose of sequestering carbon emissions is through the planting of *Pinus massoniana* from the initial investment point of view, followed by spruce.

Sedjo et al. (1995) conducted an assessment of existing studies regarding the economics of managing carbon via forestry. They report that a host of early studies have suggested relatively low carbon sequestration costs through tree planting; in many cases, under $10 per ton and rarely over $50 per ton. These, however, are only point estimates, and do not represent the problem of rising costs that are associated with involving large land areas. According to Sedjo et al., a number of more recent studies have overcome some of the limitations of the earlier analyses by:

- developing a cost function that estimates the rise in costs of capturing carbon associated with large-scale tree planting
- recognizing that land has opportunity costs
- refining the tree plantation establishment cost estimates
- utilizing discounting procedures

Results from three such studies are presented in Table 2.

Table 2 – Estimates of marginal cost of carbon sequestered by tree planting (marginal costs $/ton) (Sedjo, et al., 1995)

Study	**Total carbon sequestered (million tons per year)**				
	45	120-140	280	420	700
Moulton/Richards (1990)	9	16.57	20.69	23.24	34.73
Adams et al. (1993)	n.a.	18.5	25.11	37.21	95.06
Parks/Hardie (1995)	10.14	82.49	n.a.	n.a.	n.a.

According to Sedjo et al., there has been relatively little work done on the cost of sequestering carbon by simply using various forest management practices. The study by Hoen and Solberg (1994) suggests that thinning is not a cost effective means of sequestering carbon, while the carbon sequestration returns to forest fertilization generates marginal carbon sequestration costs of approximately $71 per incremental ton of carbon captured. Turner et al. (1993) summarize the findings of a number of studies by suggesting that the least promising silvicultural practices, from a direct carbon storage point of view, are those such as: thinning, fertilization and other stand improvement treatments.

In a seminal work on the effect of non-timber benefits on optimal timber rotations, Hartman (1976) has shown that rotations may be extended if there is some non-timber value associated with the forest. Unlike the Hartman rotation, where externality benefits are a function of the volume of timber growing on a site at any time, carbon benefits are a function of the change in biomass and the amount of carbon per cubic meter of biomass (van Kooten et al., 1995). In a study by van Kooten et al. (1992), the authors concluded that, under what they viewed as the most likely parameters, rotation ages increased by approximately 20% over the optimal financial rotation age, when no carbon costs or benefits were considered. Further research by van Kooten et al. (2000) focuses on the economics of afforestation in western Canada. The purpose of the study was to examine the potential for planting trees on marginal agricultural land as one method for Canada to achieve its CO_2 emissions reduction commitments. Forests store carbon by photosynthesis. Van Kooten et al. report that for every tonne (t) of carbon sequestered in forest biomass, 3.667 t of CO_2 is removed from the atmosphere. Carbon is stored, not only in above-ground biomass, but also in decaying material on the forest floor, in the soil and in products produced from harvested timber. Through a series of expansion factors, van Kooten et al. calculate total carbon content in hardwood and softwood timber for the given study region. They report average costs of sequestering carbon through planting hybrid poplar ranging from $18.82 per tonne, if the value of carbon is not discounted, to $32.97 per tonne, if the value of carbon is discounted at 4%. If a mix of species is planted, average cost per tonne of carbon is reported as $26.87 and $57.78 at 0% and 4% discount rate respectively. van Kooten et al. suggest that a cost of $20/tonne of carbon sequestered is a reasonable cut-off for socially desirable investment in afforestation. The authors conclude that the potential of tree plantations as an economically viable carbon sink is not clear for the case of one-time planting.

In another carbon related study, Plantinga et al. (1999) implement econometric land use models to estimate the marginal costs of carbon sequestration in Maine, South Carolina, and Wisconsin. Scenarios with and without timber harvesting are examined. Plantinga et al. express carbon flows over the course of the various scenarios in terms of present value. For the sake of the study, a present value of 30.3 (short) tons per acre was assumed as the carbon flow in a southern pine stand in the southeastern United States, assuming a sixty-year time horizon, no harvesting and a 5% discount rate. A present value of flows of 23.7 tons per acre was assumed if the forest was assumed to be harvested and replanted in year 30. Plantinga et al. find that marginal costs per metric ton of carbon sequestered range between $0 and $120, and conclude that afforestation is in deed a cost-effective strategy for offsetting CO_2 emissions.

II.2.3. Other forestry-related study

Amacher et al. (1997) conducted an economic feasibility study on the reforesting of frequently flooded agricultural lands in the Mississippi Delta. The four primary objectives of this study were:

- To estimate the net present value (NPV) of returns for alternative Delta reforestation strategies on flood-prone farmlands under representative soybean farming situations (e.g. hydrology, soils, prices and costs), and to determine whether reforesting is an economically feasible wetlands restoration option.
- To discuss how considerations other than NPV can influence landowner decisions to reforest, and landowner responses to alternative public policy designs.
- To describe policies and programs that can be developed for encouraging landowner adoption of reforestation on wetland soils as a restoration measure.
- To describe the effects of reforestation on the regional economy.

Seven possible bottomland hardwood reforestation scenarios were proposed and analyzed. The scenarios differed according to the silvicultural/planting regime appropriate for each species, differences in growth and yield, differences in soil type, and differences in rotation age. In order to compare the simulated NPVs, a common time horizon of 60 years (longest rotation) was implemented for all reforestation regimes. The NPV of reforestation for each soil type was computed using state-specific cost and return information. Estimates of the expected future prices for forest products and cost estimates for the various regimes were made. For computing NPV of forestry returns, the proportions of sawtimber to pulpwood, on various site qualities, implemented in this study are presented in Table 3.

Table 3 – Proportions of sawtimber and pulpwood by species and site class (Amacher et al., 1997)

Site Quality	Sawtimber	Pulpwood
High (all species)	75%	25%
Low (oak)	66.7%	33.4%
Low (other species)	50%	50%

Thinning was not included in any of the silvicultural regimes. Reforestation costs incorporated some or all of the following: site preparation (mechanical & labor), chemical treatment, disking (labor & mechanical), cultivation (labor & mechanical), seedling costs and planting costs. The estimated total reforestation costs per acre for the various regimes ranged from \$199.54/acre - \$ 234.24/acre. In the NPV calculation for reforestation, returns, costs, and applicable cost sharing payments were included. A real interest rate of 5% was implemented in this study. Results yielded a range of net economic returns to reforestation from \$139.44/acre to -\$176.00/acre.

II.3. Taxes, subsidies and policy design

It is important to recognize that private actions are likely to be affected by public policies that have actual or potential market implications (Sedjo et al., 1995). And so, carbon taxes and subsidies will affect the optimal forest rotation and, consequently, the carbon stored in forests (van Kooten et al., 1995).

Parks and Hardie (1995) calculate total discounted costs and employ current total carbon ratios to evaluate a specific carbon sequestration program similar to other successful environmentally motivated programs designed to change land use. They derive a supply schedule for carbon sequestered in trees planted on marginal agricultural lands in the U.S. This schedule is then used to develop criteria for enrolling lands in a national carbon sequestration program modeled after the Conservation Reserve Program. They conclude that a cost-effective program should focus on establishing softwood forests on pastureland, and select lands by minimizing cost per ton of carbon sequestered. They estimate that such a program would sequester approximately 48.6 million tons of carbon per year (3.5 % of U.S. emissions) on 22.2 million acres. Costs would include \$3.7 billion in land rental costs and forest establishment costs. Minimizing cost per acre would increase enrollment to 23.1 million acres, and would sequester 45 million tons per year, based on their analysis.

A study by van Kooten et al. (1995) examines the question of lengthening the rotation through the effect of carbon taxes and subsidies on the forest rotation when the carbon sequestered was explicitly valued. The study, which looked at forests in coastal British Columbia and northern Alberta, suggests that under some sets of timber prices, carbon values and tax/subsidy regimes, it is economically efficient never to harvest the forest, since the value of the sequestered carbon overwhelms the timber values. The proportion of carbon in biomass varies with species, although they estimate that it is in the range of 200 kilograms per m^3. Van Kooten et al. suggest that in order for forest companies to correctly take into account the external benefits and costs of their decisions, they should receive a yearly subsidy of P_cX for each m^3 of timber added to the growing stock (where: P_c = "price" or implicit social value of carbon that is removed from the atmosphere; X = (metric) tons of carbon per m^3 of timber biomass). Thus, this subsidy would be an annual subsidy equal to the total value of the carbon sequestered that year.

Van Kooten et al. suggest that forest companies should face a tax levied at harvest time that equals the external cost of the carbon released to the atmosphere. The tax would be equal to $P_cX(1-B)$ per m^3 of timber harvested (where: B = fraction of timber that is harvested, but goes into long-term storage in structures and landfills).

Hoen and Solberg (1997) propose a carbon tax/subsidy scheme, and analyze how such a scheme would impact forest rotation ages. For the sake of their study, Hoen and Solberg assume that subsidies are paid at the time of carbon sequestration and that taxes are imposed at the time of decay. The authors suggest that, if the subsidy/tax regime is connected to the stock, it would not be proper to use a once and for all payment (lump sum) at the time of harvest, but rather to pay a smaller amount on a per period basis. This would create (correct) incentives for promoting actions that extend/delay the decay of the carbon already sequestered. A lump sum payment, on the other hand, similar to how timber is valued at harvesting, would generate counterproductive incentives, as it, at the margin, would represent a substantial cost to increase the rotation age and postpone the payment related to the carbon sequestered. Hoen and Solberg present results from a numerical simulation, where both timber and CO_2 benefits and costs are valued for a timber rotation of spruce. The results suggest that the optimal rotation age increases with increasing CO_2 price. The results further indicate that, under moderate CO_2 prices, the optimal rotation age decreases when the real rate of return increases.

Sullivan and Amacher (1999) develop a framework that links landowner and regional impacts of land use shifts from agriculture to forestry in the Mississippi Delta, in order to compare economic impacts of land use changes at landowner and regional levels, and to investigate the self-financing potential of subsidies. They conclude that, for limited combinations of tree species and soil type (better soils), landowner subsidies could be self-financing, providing tax revenues that could offset government outlays. Furthermore, if subsidies were adopted, they should target specific species and site conditions.

II.4. Summary of economic- and subsidy-related studies

The economic feasibility study by Kronrad et al. (2002) appears, at this stage, to be the only study that directly considers the economic implications of planting and managing forests on abandoned mined lands. Their study, however, focuses on establishing forests on abandoned mined lands, and not on converting reclaimed mined lands to forests. Their study also considers only one hardwood species for reforestation.

The cost of sequestering carbon through forestry appears to be fairly well documented in the literature. This "cost of sequestering carbon", however, is not a clearly defined concept, and seems to vary somewhat from study to study. It would seem that, in general, the early research studies tended to estimate the initial costs of establishing a carbon sequestering forest at one point in time, and compare it with the cumulative carbon captured over the life of the forest, often abstracting from follow-on costs, custodial costs and land costs. More recent sophisticated approaches have tended to make use of a discounted present value of establishment costs. This discounted cost is then used to estimate the cost per ton for sequestering carbon (Sedjo et al., 1995). The costs of sequestering carbon, as reported in the literature, range from $0/ton of carbon to $120/ton of carbon, although the majority of studies suggest a cost below $50/ ton of carbon, with van Kooten et al. (2000) suggesting a cut-off cost of $20/ton of carbon sequestered. However, the economic implications of sequestering carbon, specifically on mined lands, is not a well-researched area. Kronrad et al. approach the carbon sequestration issue from a different angle. They assume various values of carbon, and analyze how these various values affect the profitability of planting and managing forests on abandoned mined lands. The studies by van Kooten et al. (1995) and by Hoen and Solberg (1997) both address the impact of a carbon tax/subsidy scheme on the optimal forest rotation. Both studies suggest a periodic (annual) carbon subsidy payment, as a means of delaying harvest, and in so doing, extending the decay of carbon already sequestered.

Thus, there appears, at this stage, to be a lack of research pertaining specifically to the conversion of reclaimed mined lands from their current use to forests, and the economic implications of such a land use conversion. More specifically, the only piece of literature that does address a similar topic considers only one hardwood species for reforestation, and only uses growth and yield models developed for non-mined land, and not actual data pertaining to growth on mined lands. This reforestation concept needs to be extended to other hardwood and softwood species, and needs to be based on silvicultural prescriptions that are specifically designed for mined sites. Furthermore, the potential for a variety of incentive schemes, aimed specifically at promoting the conversion of reclaimed mined lands to forests, has yet to be explored in depth. As opposed to calculating the economic feasibility of various reforestation regimes based on assumed carbon prices, it may be more useful (for policy makers) to gain an idea of what the value of carbon would need to be in order to render a given land-use conversion profitable to the landowner. Policy makers could then use these carbon values to establish real carbon subsidies.

II.5. Survival rates of planted trees

Planting stem density is a controllable variable in establishing a forest plantation. However, the percentage of trees that survive until harvest age varies considerably from one plantation to the next. Thus, when basing an economic analysis on the value of standing timber at harvest age, an estimate of planting success (tree survival), based on initial tree planting density, is necessary. Research has been conducted with regards to the survival of hardwoods and pines on mine and non-mined land, both in natural stands and plantations. However, most of the available literature pertaining to the survival of trees in plantations deals with the first few growing seasons subsequent to planting, and not the survival over a complete rotation. The data revealed in the pertinent literature also varies substantially.

II.5.1. Hardwoods

Plass (1975) reported on a direct seeding experiment, established on two graded mined sites in 1965. The four-year survival rate for scarlet oak was 85%. Plass (1977) also gathered 10-year survival data (Table 4) from an experiment in which commercially valuable species were planted on surface-mined land. The average 10-year survival rate for these hardwood species was 63.4%.

Table 4 – 10-year survival rates for various hardwood species planted on surface mines (Plass, 1977)

Species	**10-yr survival %**
American Sycamore	53
Sweetgum	65
White Ash	92
Cottonwood	40
Yellow Poplar	67

Table 5 – 5-year and 11-year survival rates for various hardwood species on mined soils (DenUyl, 1955; 1962)

Species	**5-yr survival %**	**11-yr survival %**
Green Ash	82	66
Cottonwood	67	57
Red Maple	66	50
Black Locust	83	74
Tulip Poplar	29	24
Sycamore	74	67
Sweetgum	69	55

In a similar study to that of Plass (1977), Purdue University and the Indiana Coal Association, in 1949. conducted an experiment in order to test ten commonly planted hardwood species on strip-mine spoil banks in Indiana. Survival rates for some of the tested species, as reported by DenUyl (1955; 1962), are summarized in Table 5. The average 5-year and 11-year survival rates for these hardwood species are 67% and 56%, respectively.

In 1946 and 1947, the U.S. Forest Service established species trials on eastern and southeastern Ohio surface-mined land (Larson and Vimmerstedt, 1983). In 1975 and 1976, Larson and Vimmerstedt measured these plantings in order to gather long-term growth information. The 30-year survival rates for some of these species trials are reported in Table 6.

Table 6 – 30-year survival rates for hardwood species trials in Ohio on mined soils (Larson and Vimmerstedt, 1983)

Species	**30-yr survival rates**
Green Ash	52
White Ash	56
Black Locust	23
Tulip Poplar	20
Red Oak	13
White Oak	8

Also in 1947, Deitschman (1950) conducted a test to determine the growth and survival rates of various commercial hardwood species planted under three different cover types (shortleaf pine, black locust, and no overstory) on strip-mined land in Southern Illinois. Third year survival rates for sweetgum and ash under no overstory were 74% and 86% respectively. Ashby (1999) reports survival rates of white oak and red oak seedlings planted on ungraded cast overburden in Southern Illinois (Table 7).

Table 7 – Percent of Fall- and Spring-planted white and red oak seedlings, established at age 3 on mined soils, that survived to age 11 – 16 years (Ashby, 1999)

	Survival %	
Season planted	**White oak**	**Red oak**
Fall	85	98
Spring	79	95

A number of studies of forest plantations on mined land have been conducted in Pennsylvania. The Pennsylvania Department of Fish and Waters started an experimental planting on anthracite coal spoil in 1944 and 1945. Mickalitz and Kutz (1949) reported first year survival rates of 70% for red and white oak, and 61% for black locust. Czapowskyj (1970) reported a 59% 12-year survival rate for black locust planted on various mine spoil types in the anthracite region of Pennsylvania. Schuster and Hutnik (1983) reported 35-year survival rates of 60% and 66% for hybrid poplar and red oak respectively. These trees were amongst a number of species planted on various sites in the bituminous coal region in Pennsylvania as species trials, in order to identify species suitable for planting on mine spoil.

Planted trees growing on reclaimed mined lands are generally subjected to stresses resulting from the relatively inhospitable soil chemical and physical environment, competition from other vegetation, and even herbivory from animals. Demchik & Sharpe (1999) conducted a study to determine whether lime and fertilizer, fencing and vegetation control could increase the growth and survivorship of natural northern red oak seedlings on an extremely acidic site in southwestern Pennsylvania. The results of their study are summarized in Table 8.

Table 8 – The effect of all possible combinations of lime and fertilizer, vegetation control (weed), and fencing on annual percentage mortality of northern red oak seedlings during the first, second and third growing seasons (Demchik & Sharpe, 1999)

			Annual mortality (%)		
Lime & Fertilizer	**Weed**	**Fencing**	**Year 1**	**Year 2**	**Year 3**
No	No	No	0	7	23
No	No	Yes	0	13	27
No	Yes	No	0	25	65
No	Yes	Yes	0	0	27
Yes	No	No	0	7	37
Yes	No	Yes	0	0	15
Yes	Yes	No	0	0	30
Yes	Yes	Yes	0	10	23

II.5.2. White pine

In an experiment conducted in Kentucky, seven pine species were seeded on various spoil types (Plass, 1974). It appeared that early survival rates were not affected by spoil texture. White pine was reported as having the highest overall survival rates on both coarse (89%) and fine material (95%). In another study, Plass (1977) reports a 78% 10-year survival rate of white pine planted on surface mine spoils in Kentucky. In a similar short-term growth study, Brown (1962) surveyed 2- to 12-year-old planted stands of various species on mine spoils in West Virginia. White pine was reported to have a survival rate of 69%.

In 1946 and 1947, the U.S. Forest Service established species trials on strip-mined land in eastern and southeastern Ohio (Larson and Vimmerstedt, 1983). In 1975 and 1976, Larson and Vimmerstedt measured these plantings in order to gather long-term growth information. The 30-year survival rate for white pine was 27%. In another long-term growth study, Dierauf and Scrivani (1995) conducted a study of white pine in the mountains of Virginia. Over a period of 30 years, a total of 112 measurements of 59 plots in 48 different plantations were made. Survival rates were calculated over a range of stand ages. The average survival percentage was 55% at an average stand age of 29 years.

In 1899, a 5.6-acre white pine stand was established in an abandoned pasture in North Carolina. Approximately 3800 three-and four-year-old seedlings were hand-planted per acre. The survival data collected from this pioneering case study in the Old Orchard white pine Plantation in North Carolina is summarized in Table 9.

Table 9 – Survival data for study plots in the Old Orchard Plantation, Biltmore Estate, spring 1999, at plantation age 100 years (McNab and Ritter, 2000)

Plot treatment	**Site index (ft)**	**Survival %**
Thinned	71	2.3
Unthinned	75	4.4
Unthinned	56	7.4

Initial average tree density on the two unthinned plots has been reduced by natural mortality. No mortality, however, has occurred from competition on the thinned plot since age 24 (McNab and Ritter, 2000).

Survival data from studies dealing with non-mined land is also useful, as the following two studies prove that survival data does not vary that much from studies conducted on mined lands. Sluder (1963) reports the findings of a white pine provenance study in the Southern Appalachians. Three white pine plantations were established in 1959 in North Carolina, Georgia and Virginia. The planting areas in Virginia and Georgia were old fields, while the North Carolina planting area was part of a large pasture. Average survival after the first, second, and third years for the three plantations are summarized in Table 10.

Table 10 – Average survival for first, second and third growing seasons (Sluder, 1963)

Plantation	1st year	2nd year	3rd year
North Carolina	90%	85.1%	85.1%
Georgia	59.7%	56.1%	55.5%
Virginia	82.8%	80.7%	79.6%
Average	77.5%	73.97%	73.4%

In 1957, a number of pine species were planted on an old-field site in the Piedmont near Union, South Carolina. The 13-year survival rate reported for Eastern white pine was 52% (Branan & Porterfield, 1971).

II.6. Growth and yield on reclaimed mined lands

The Surface Mining Control and Reclamation Act of 1977 (SMCRA) mandates that U.S. coal-mining companies reclaim mined land in a fashion that renders the land at least as productive after mining as it was before mining (Torbert et al., 1995). The potential of these surface mines to be reclaimed in such a way that the pre-mining productivity of these lands is equaled or improved upon is of utmost importance to the long-term success of landowner objectives.

In 1962, W.G. Jones established a 2-acre stand of hybrid poplars on a reclaimed strip-mine in Clearfield County, Pennsylvania. After 16 growing seasons, the stand was harvested. Approximately 600 trees were harvested from the plantation. Total yield from the harvest was approximately 90 tons of pulpwood bolts, and 9400 board feet of lumber (Davidson, 1979). In another study in Pennsylvania, Davidson (1981) reported growth and yield data for 22 plantings by the Morris Run Coal Company, from 1919 to 1938. 7975 m^3 were harvested from 61 ha, of which planted species comprised 5394 m^3, and volunteer species 2646 m^3. White pine produced 77 m^3 ha^{-1}. According to Davidson, the sites produced average timber volumes when compared to similar plantings on old-field sites. Davidson et al. (1990) reported findings of a surface mined area in the Southern Anthracite Coal Field of Pennsylvania, which was successfully planted to northern red oak. They conclude that "the oaks in this planting have survived well, and are growing at a rate equal to or better than plantations on undisturbed sites."

Burger et al. (1998) support the findings by Davidson et al. (1990). According to Burger et al., reclaiming mined land for forestry is compelling because the productivity of forests and value of wood can be greater than that prior to mining. The paper was aimed at providing evidence to support intensive site preparation and management of mined soils in an effort to reclaim these lands successfully thorough reforestation. The research data presented in Table 11 illustrates the effects of reclamation technique on white pine productivity. The results suggest that, whereas the average site index of an undisturbed Appalachian forest site is approximately 55ft (base age 25 years), and average harvest volume at age 30 is approximately 35.1 MBF/acre, a properly reclaimed mined site could attain a site index of 70ft (base age 25 years), and produce a harvest volume of 46.4 MBF/acre.

Table 11 - The effects of reclamation technique on white pine productivity (Burger et al., 1998)

White pine site type	**Site index (Base age 25)**	**Bd. Ft. Vol. At age 30 (MBF/ac)**	**Harvestable wood products**
Average quality of undisturbed Appalachian forest site	55	35.1	Small sawtimber
Projected average quality of post-SMCRA reclaimed mine soil	45	6.1	Pulp
Actual quality of properly reclaimed mine soil in Virginia	70	46.4	Large sawtimber

Another study supporting the idea that mined sites can be equally productive as their non-mined counterparts is that by Rodrigue (2001). Using 14 mined and 8 non-mined forested sites (mixed hardwoods and pine species) in the midwestern and eastern coalfields, Rodrigue undertook a research project with the following objectives: (i) characterize the development, composition, and diversity of woody species on pre-SMCRA, forested surface mined land; (ii) estimate forest and site productivity on surface mined land and determine the soil and site properties most influencing forest growth; (iii) estimate rotation-age timber product value; (iv) quantify current carbon sequestration pools associated with the developing woody plant biomass, the forest floor, and developing soil medium; and (v) compare the diversity, forest and site productivity, commercial value, and carbon capture of reclaimed mined sites to that of regional non-mined forest systems. Results of his study suggest that forest productivity of pre-SMCRA mined sites can be equal to or greater than that of non-mined forests, with MAI ranging between 3.3 $m^3ha^{-1}yr^{-1}$ and 12.1 $m^3ha^{-1}yr^{-1}$. His study showed that six of the 14 mined sites were more productive than their non-mined counterparts, seven mined sites were as productive, and only one mined site was less productive.

According to Burger and Zipper (2002), studies on the Powell River Project in S. W. Virginia show that mine soils covering a wide range of quality have been constructed by mining operations under SMCRA. This productivity spectrum is represented by sites on which trees are unable to survive, to sites on which trees are growing at rates faster than on natural, undisturbed soils. Burger and Zipper report white pine growth by age 30 on mine soils of different depths and different site classes (Table 12). These results suggest that as site index increases, harvest volumes tend to increase exponentially. Hence, intensive site preparation in converting reclaimed mined lands from grasslands to forests would seem advisable in terms of forest productivity.

Table 12 – White pine growth by age 30 on different mine soils (Burger and Zipper, 2002)

Mine soil depth (inches)	**Site index (ft at base age 50)**	**Standing timber volume at age 30 (MBF/acre)**	**Wood products**
12	60	5	Mine props/pulp
24	80	14	Small sawtimber
48	100	32	Large sawtimber

According to Plass and Burton (1967), results from Forest Service experimental plots in Alabama, Tennessee and Kentucky suggest that the growth of pine trees on spoil areas will not be as fast as on good pine sites, but it may be equal to, or exceed the growth on eroded, abandoned farmland or similar areas that have shallow soils. Experimental plantings on land mined and reclaimed by the Marigold Coal Company near Jasper, Alabama, illustrated the growth potential of pine trees on spoil areas. After 20 growing seasons, Plass and Burton found that merchantable pulpwood averaged 20 cords per acre for loblolly pine, 17 cords for shortleaf pine and 6 cords for longleaf pine.

In another experimental planting, Zeleznik and Skousen (1996) reported tree volumes from three 46 year-old plantations on reclaimed mines in Ohio. On leveled sites, white ash produced 347m^3 ha^{-1}. On unleveled sites, white as volumes averaged 231.5 m^3 ha^{-1}. Tulip poplar volumes were 39 m^3 ha^{-1} on leveled sites and 298 m^3 ha^{-1}on unleveled sites. White pine volumes were 189 m^3 ha^{-1} on leveled sites and 213 m^3 ha^{-1} on unleveled sites. The results suggest that, in general, volume growth is better on unleveled sites.

II.7. Summary of survival- and growth and yield-related studies

Research has been conducted regarding the amounts and values of timber produced on reclaimed mined lands. The potential of these surface mines to be reclaimed in such a way that the pre-mining productivity of these lands is equaled or improved upon, is well-documented. A number of studies have also been conducted, pertaining to the survival of planted trees on mined lands. The literature suggests a broad spectrum of survival rates.

CHAPTER III - METHODS

III.1. Introduction

It is not sufficient to know how much timber volume could potentially be grown on reclaimed mind lands, or to know that reclaimed mined lands can potentially produce greater volumes of timber than undisturbed land. These are important biological facts, but do not render the conversion of reclaimed mined land to forests an economically feasible option.

In order to calculate the financial feasibility of a given silvicultural regime for a particular site, it is necessary to know: 1) the volume of timber available at a given rotation age, 2) the mix of merchantable sawtimber and pulpwood at harvest, 3) the value of the timber and pulpwood, 4) the value of any other associated amenity values and opportunity costs, 5) the costs associated with implementing the given regime and 6) the timing of costs incurred and revenues received.

Considering the economic profitability of converting reclaimed mined lands to forests entails comparing the expected net financial returns from forest production to any opportunity costs associated with the land-use conversion. To compare the potential profitability of alternative reforestation strategies, net present values (NPV – for single rotation) and land expectation values (LEV – for multiple rotations) are simulated for the various silvicultural regimes. These measures of economic feasibility are simulated for a range of scenarios, by varying: site preparation intensity, timber and pulpwood prices, rotation lengths, site class and alternative rate of return. Further, various incentive schemes are explored, in an effort to determine what financial remuneration would be necessary in order to render a given scenario economically feasible.

III.2. Data

The bulk of this financial feasibility study begins with forest inventory data collected on reclaimed mined sites that were taken from a study by Rodriguez (2001). These data were gathered from fourteen planted forest sites across seven states, located on reclaimed mined lands in the midwestern and eastern coalfields (Figure 1).

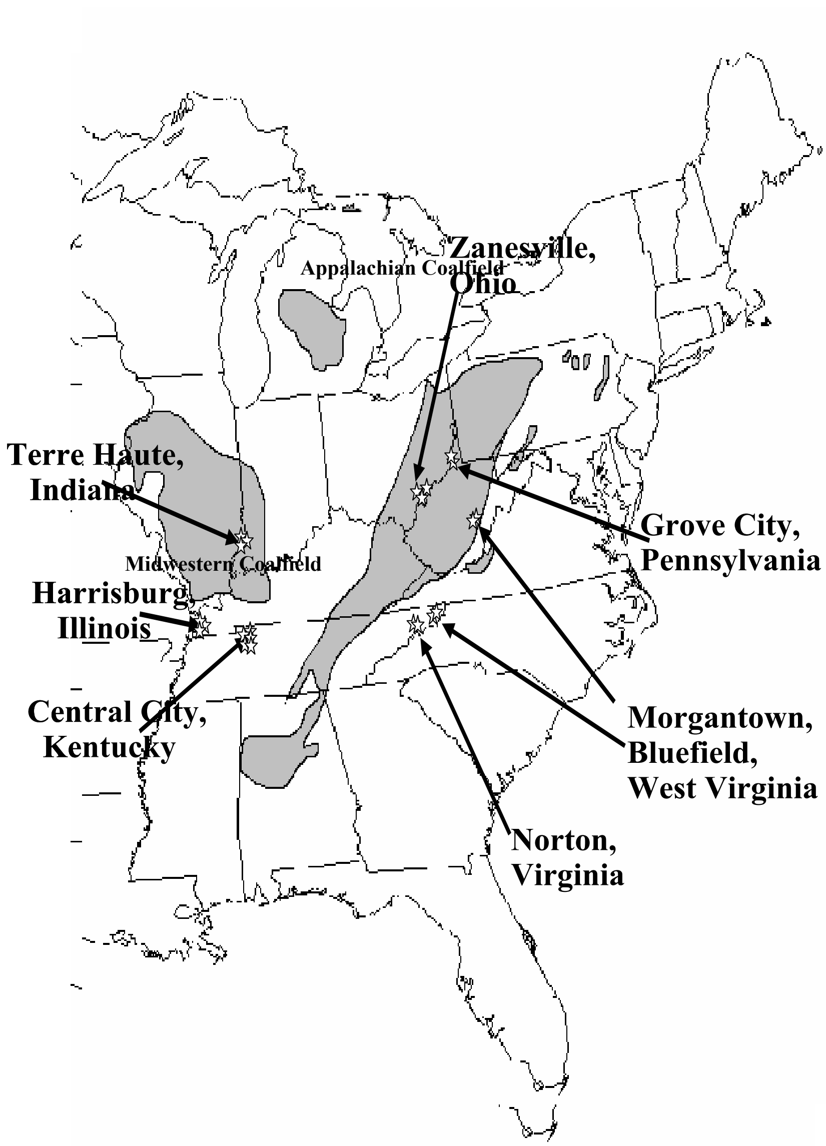

Figure 1 – General location of study sites in the midwestern and eastern coalfields

Within each similar geographic region (e.g., southern Illinois), reference native forest sites representing minimally manipulated regional forests were also located and measured. In total, eight reference sites were located within the seven state study area. From hence forth, these reference sites will be referred to as non-mined or "natural" sites.

III.3. Growth and yield model formulation

Two forest stand types are considered for reforestation purposes: 1) mixed Appalachian hardwoods and 2) white pine. Therefore, the Rodriguez data were first divided into hardwood stand data and pine stand data. A growth and yield model of the following form was then developed for each of these sets of data:

$$\ln(V) = b_0 + b_1 S + b_2 N + b_3 / A + e$$

Where:

V = total stand volume (m^3/ha)

S = site index

N = stand density at harvest (stems/ha)

A = stand age (years)

e = random error

This variable-density growth and yield equation is similar to the prediction model developed by MacKinney and Chaiken (1939) for natural stands of loblolly pine. The primary difference between our model and that of MacKinney and Chaiken is that our stand density (N) is measured in stems/ha, whereas their stand density (log SDI) is presented as the logarithm of a stand density index.

Site indices that were identified by Rodriguez for the mixed hardwood stands were converted to site indices for white oak (base age 50 years), and site indices for the pine stands were converted to site indices for white pine (base age 50 years) using a site index comparison graph for species on the same land in the Southern Appalachians (Doolittle, 1958).

III.3.1. Survival of planted trees

The stand density variable, used in the yield equations that were estimated for this study, is stand density at harvest. Thus, given the fact that planting density will be a controlled factor in the conversion of these reclaimed mined lands, survival equations (Table 13) were developed for both mixed hardwoods and white pine, based on stand age, in order to calculate stand density at harvest from the pre-determined planting density. Hence, stand density at harvest is a function of planting density and harvest age. The mixed hardwood survival equation developed for this study is based on survival data from the following previous studies: Mickalitz and Kutz (1949), Deitschman (1950), DenUyl (1955), Czapowskyj (1970), Plass (1975), Larson and Vimmerstedt (1976), Plass (1977), Larson and Vimmerstedt (1983), Schuster and Hutnik (1983), Ashby (1999) and Demchik and Sharpe (1999). The white pine survival equation developed for this study is based on survival data from the following previous studies: Brown (1962), Sluder (1963), Branan (1971), Larson and Vimmerstedt (1976), Plass (1977) and Dierauf Scrivani (1995).

Table 13 – Survival equations

Species	**Survival equation**
Mixed hardwoods	y = -8.688ln(A) + 84.472 + e
White pine	y = -15.044ln(A) + 101.09 + e

Where:

y = survival %

A = stand Age (years)

e = random error

Table 14 – Regression statistics for survival equations

	Data set	
	Mixed HDWDS	**White pine**
ln(A)		
Coefficient	**-8.68844**	**-15.04359**
t-stat	-3.40477	-6.05245
P-value	0.00392	0.00000
Observations	17	104

The survival equations (Table 13) were estimated using ordinary least squares regressions on the published survival data. The corresponding regression statistics for these survival equations are summarized in Table 14. The data used in developing these survival equations are illustrated in Figures 2 and 3.

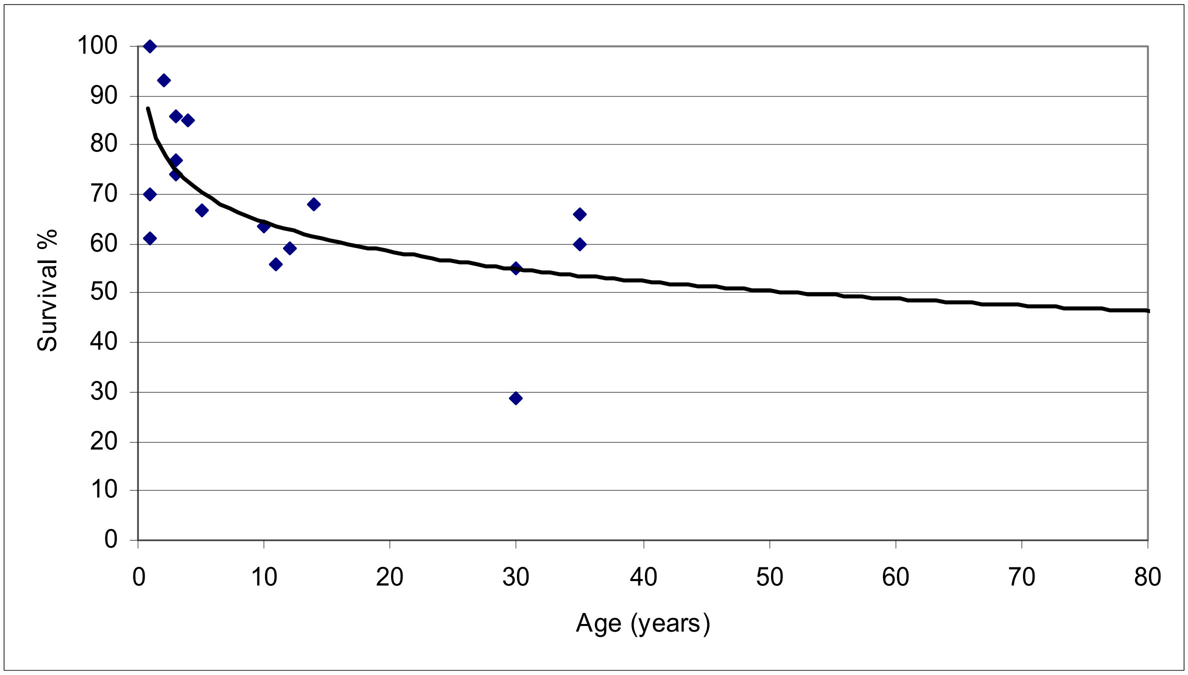

Figure 2 – Survival curve for mixed hardwoods

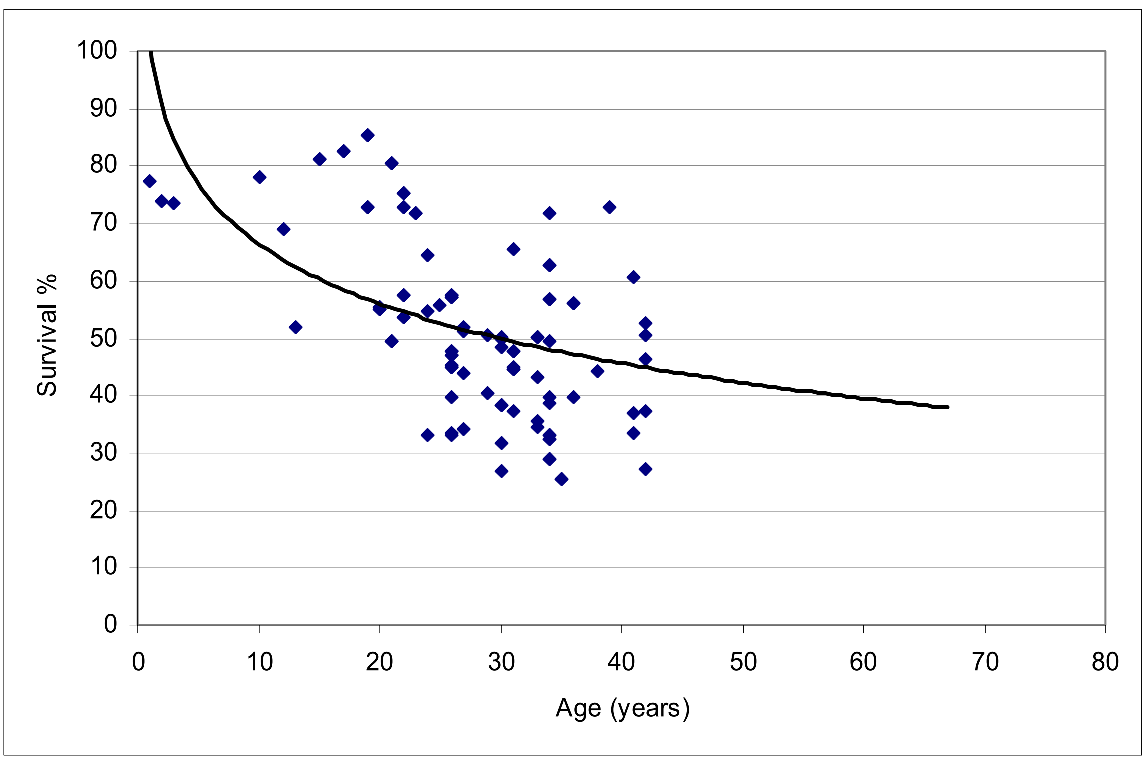

Figure 3 – Survival curve for white pine

The literature suggests that survival of planted trees may range from 0% to almost 100%, depending on the specific planting scenario, as there are many factors which determine the survival of a tree. Hence, it is understood that no one survival equation will yield an accurate estimate for all given scenarios. The survival equations developed for the sake of this study simply provide an approximation of survival percentage for the sake of data manipulation for this study.

III.3.2. Stand volume

Multiple linear regression was used to estimate per hectare stand volume, with ln(V) as the dependent variable, and S, N and A^{-1} as the independent variables. The growth and yield models estimated for mixed hardwoods and white pine are presented in Table 15. The corresponding regression statistics for these equations are presented in Table 16.

Table 15 – Estimated yield equations for mixed hardwood and white pine plantations on mined land (based on data from study by Rodrigue (2001))

Species	**Yield equation**
Mixed hardwoods (pooled data)	$\ln(V) = 4.862 + 0.015S - 0.0002N - 11.229/A + e$
Mixed hardwoods (mined data only)	$\ln(V) = 6.156 + 0.006S - 0.0003N - 34.400/A + e$
White pine	$\ln(V) = 5.328 + 0.016S - 0.0004N - 34.131/A + e$

Where:

V = total stand volume (m^3/ha)

S = site index

N = stand density at harvest (stems/ha)

A = stand age (years)

e = random error

Table 16 – Regression statistics for yield equations

	Data set		
	Mixed HDWDS (pooled)	**Mixed HDWDS (mined only)**	**White pine**
Site index (S)			
Coefficient	**0.0145****	**0.00570**	**0.01604****
t-stat	2.90857	0.54625	3.13600
P-value	0.00529	0.59065	0.00448
Stand density (N)			
Coefficient	**-0.00023**	**-0.00025**	**-0.00038**
t-stat	-0.86142	-0.60100	-1.50392
P-value	0.39289	0.55427	0.14565
Age (1/A)			
Coefficient	**-11.22905**	**-34.39954***	**-34.13108****
t-stat	-1.03875	-1.97406	-3.81126
P-value	0.30364	0.06167	0.00085
Observations	57	25	28

* indicates coefficient is significant at $\alpha = 0.10$ level
** indicates coefficient is significant at $\alpha = 0.01$ level

Rodrigue (2001) reported that comparisons of forest productivity between mined and non-mined mixed hardwood stands suggest that mined sites, if managed correctly, are capable of being just as, if not more productive than their non-mined counterparts. Hence, a regression was run initially on the pooled mined and non-mined mixed hardwood data, with a dummy variable distinguishing between mined and non-mined data. The results suggested that the yields from the mined and non-mined sites were not significantly different. Thus, the mined and non-mined mixed hardwood data were pooled to allow for a larger data set. A growth and yield model was also developed for mixed hardwoods, based on the mined data only. This model, however, yielded higher volumes than the model developed for the pooled mined and non-mined data. The model for the pooled data was implemented in the rest of this study. Rodrigue did not present any data for non-mined white pine stands. Hence, we have not distinguished between mined and non-mined white pine data.

III.4. Silvicultural treatments

Restoration of productive forest land requires the construction of a deep, non-compacted, non-toxic minesoil, and the absence of a competitive ground cover (Torbert et al., 1996). The three proposed silvicultural treatments for this study are aimed at sequentially addressing the three major factors limiting reforestation success on reclaimed mined land:

- incompatible ground cover
- soil compaction
- incompatible soil chemical properties and low fertility

Silviculture treatment 1 (low intensity) - This treatment addresses only the existing incompatible ground cover. The following silvicultural activities are assumed: Herbicides will be used to kill the existing groundcover, trees will be planted, and herbicides will be used as necessary to control competing vegetation adjacent to the planted trees.

Silviculture treatment 2 (medium intensity) - This treatment will address the existing incompatible groundcover and soil compaction problems The following silvicultural activities are assumed: Herbicides will be used to kill the existing groundcover, the site will be tilled to a depth of 0.7m in one direction to ameliorate soil compaction problems, trees will be planted, and herbicides will be used as necessary to control competing vegetation adjacent to the planted trees.

Silviculture treatment 3 (high intensity) – This treatment will address the existing incompatible groundcover, soil compaction and soil chemical and fertility problems. The following silvicultural activities are assumed: herbicides will be used to kill the existing groundcover, the site will be tilled to a depth of 0.7m in one direction to ameliorate soil compaction problems, soil chemical and fertility problems will be corrected/improved through liming and fertilization, trees will be planted, and herbicides will be used as necessary to control competing vegetation adjacent to the planted trees.

III.5. Estimation of reforestation costs

In order to estimate the costs of converting reclaimed mined lands from grasslands to forests under the various silvicultural regimes, cost estimates were made for each of the three site preparation intensities. The activities and costs associated with each of the three site preparation intensities are reported in Table 17. A number of these costs are average costs from the literature, while some of them were collected via personal communication. The total costs incurred per site preparation intensity for the mixed hardwood and white pine scenarios, are summarized in Table 18.

Table 17 – Estimated costs of various site preparation activities in given year

	Activity	Cost ($/ha)	Site preparation intensity
Year 0	Weed control (herbicide + application)	262.54[1]	High, medium, low
	Ripping (D8 bulldozer)	296.52[2]	High, medium
	Fertilize (6oz/tree: materials + application)	197.16[3]	High
	Lime (2.47 tons/ha: materials + application)	97.23[4]	High
	Seedlings ($0.25/tree: mixed hardwoods)	369.66*[5]	High, medium, low
	Hand planting	672.11[6]	High, medium, low
Year 1	Weed control 1 (herbicide + application)	90.19[7]	High, medium, low
	Weed control 2 (herbicide + application)	90.19	High, medium, low
Year 2	Weed control 1 (herbicide + application)	90.19	High, medium, low
	Weed control 2 (herbicide + application)	90.19	High, medium, low
	Fertilize (12 oz/tree)	237.49	High

* $0.20/tree for White pine = $268.84/ha

Table 18 – Total costs incurred per site preparation intensity

Site preparation intensity	**Total cost ($/ha – not discounted)**	
	Hardwoods	***White pine***
Low	1665.08	1591.15
Medium	1961.60	1887.67
High	2493.48	2419.55

[1] 1.25 gal/ac @ $45/gal + application @ $50/ac (tractor sprayer)
[2] D8 bulldozer @ $120/ac
[3] Walmart (2003): $4/50lbs bag of 10:10:10 + application @ $7/hr (labor wage)
[4] Sisson & Ryan Quarry (2003): $4.35/ton of lime + application @ $35/ac (farm tractor)
[5] Forest Landowner 2001-2001 Seedling Nursery Directory
[6] 1344 trees/ha @ $0.5/tree
[7] 0.5gal/ac @ $45/gal + application @ $14/ac (hand spray)

These site preparation costs are similar to those estimated by Kronrad et al. (2002) for their study on reclaiming mined lands to forests in a number of States.

III.6. Net Present Value and Land Expectation Value calculations

For the sake of this study, net present values (NPV) and land expectation values (LEV) will be calculated as measures of economic feasibility of various land-use conversion scenarios. All results will be presented and discussed in terms of LEV. However, NPV results will be presented in Appendix A. NPV recognizes money's time value by using the minimum acceptable alternative rate of return to discount all revenues and costs back to the time of project initiation. The discounted costs are then subtracted from the discounted revenues as shown below:

NPV = present value (revenues) – present value (costs)

The general formula used in calculating NPV values is as follows:

$$\text{NPV} = \sum_{t=0}^{T} R_t/(1+i)^t - \sum_{t=0}^{T} C_t/(1+i)^t$$

Where:

R_t = revenue received at time t ($/ha)

C_t = cost incurred at time t ($/ha)

i = alternative rate of return

t = time since project initiation (years)

T = harvest age (years)

LEV is the NPV for an infinite time horizon. Whereas NPV takes into account the opportunity cost of money that is tied up in the investment in forestry over a single rotation, LEV also takes into account the opportunity cost of land by considering subsequent rotations. Put simply, calculating LEV is similar to assuming that a project will be replicated an infinite number of times into the future. This is the underlying assumption in reforesting these abandoned mine lands; hence the calculation of LEV. The general formula used in calculating LEV values is as follows:

$$\text{LEV} = [\sum_{t=0}^{T} R_t/(1+i)^t - \sum_{t=0}^{T} C_t/(1+i)^t]/(1-(1+i)^T)$$

More often than not, there is an opportunity cost of land in another use involved in the conversion of land from one use to another. The mined lands of relevance in this study are those that have already been reclaimed to grasslands. With very little opportunity for alternative uses, one may expect these lands to be used for grazing. However, in most cases, often due to the steep terrain, these lands are not put to use at all, and are simply abandoned. Hence, in converting such lands to another land use, there is no opportunity cost of land in another use involved. This will remain the assumption throughout this study.

A wide variety of decision parameters must be considered when examining the financial feasibility of reforesting mined lands, including: rate of return, timber and pulpwood prices, rotation age and site class. All NPV and LEV calculations were conducted under the assumption of an initial planting density of 1344 stems/ha. This is a standard 10 x 8 ft stocking for plantations. A sensitivity analysis was conducted by varying the following factors:

- *Alternative rate of return (ARR):* Scenarios were developed, using 3.5%, 5%, 7.5% and 10% as alternative rates of return. This range of alternative rates of return covers a broad spectrum of interest rates, and is consistent with other studies.
- *Timber and pulpwood prices:* Two sets of prices were used. For the sake of convenience, we will label these two sets of prices: (1) Low prices and (2) High prices. The first set of prices used (low prices) were 1st quarter 2003 Timber Mart-South standing timber average prices for mixed hardwoods and pine in Virginia (Table 19). The second set of prices used (high prices) in our analysis comprises a set of ideal, high-end prices, where only high-value timber species and top quality timber products are considered. Standing timber prices from the 2003 Pennsylvania Woodlands timber market report were averaged for the following hardwood species: red oak, white oak, black cherry, white ash, yellow poplar and sugar maple (hard maple). An average of $379.63/MBF was calculated and converted to a $/ton value. The white pine timber price used in the second set of prices is that quoted by Truman Lumber Company (July 2003). This price was used in an effort to represent the potential value of white pine sawtimber, were it to be sold in a "niche market," and had a range of $100 - $200/MBF. The high-end of this range was chosen for our "high-end, ideal scenario", and converted to a $/ton value. Truman Lumber Company did not place a value on white pine pulpwood. Both the hardwood and white pine pulpwood prices are those taken from the Pennsylvania Woodlands timber market report. This second set of prices is presented in Table 20.

Table 19 – Low prices - 1st Quarter 2003Timber Mart-South standing timber average stumpage prices for Virginia ($/ton)

	Hardwoods	Pine
Sawtimber	20.07	29.68
Pulpwood	4.65	8.51

Table 20 – High prices - Pennsylvania Woodland timber market report (2003) and Truman Lumber Co. ($/ton)

	Hardwoods	Pine
Sawtimber	61.04	34.64
Pulpwood	9.05	11.89

- *Rotation age:* Hardwood rotation ages were varied, in increments of 10 years, from 40 – 80 years. Pine rotation ages were varied, in increments of 5 years, from 20 – 40 years. These rotation age ranges cover a spectrum of feasible rotation ages for hardwoods and softwoods, respectively.
- *Site class:* Economic feasibility calculations were made for each of the three site preparation intensities on each of the designated site classes I-V.

The purpose of this sensitivity analysis was to analyze how varying any of these factors affected the decision-making process in the quest for the optimal management regime.

III.7. Site classes

NPV and LEV values in this study are reported for each site preparation intensity on each site class. Tables 21 and 22 show the site class delineations used in this study.

Table 21 - Site index classes for mixed hardwoods (ft at base age 50)

Site Class	**V**	**IV**	**III**	**II**	**I**
Range	< 51	52-61	62-71	72-80	80 +
Average	46	56	66	75	85

Table 22 - Site index classes for white pine (ft at base age 50)

Site Class	**V**	**IV**	**III**	**II**	**I**
Range	< 64	65-77	78-88	89-99	100 +
Average	58	71	83	94	106

When forest sites are harvested, landowners tend to merchandise their products by selling larger logs as sawtimber and smaller pieces of wood as pulpwood. The proportions of these products often depend on species and site quality. On higher quality sites, the proportion of sawtimber tends to be higher and vice versa on poorer sites (Amacher et al., 1997). For the sake of this study, site classes I and II were classified as high quality sites. Site classes III, IV and V were classified as poor quality sites. Based on these assumptions, the proportions of sawtimber and pulpwood shown in Table 23 were used in this study.

Table 23 - Proportions of sawtimber and pulpwood for various site classes by species (Amacher et al., 1997)

Site Class	**Sawtimber**	**Pulpwood**
I & II (HDWDS & Pine)	75%	25%
III, IV & V (HDWDS)	66.7%	33.4%
III, IV & V (Pine)	50%	50%

Competition control, fertilization and ripping can have significant effects on the growth of a forest stand. In a study by Will et al. (2002), a difference of approximately 18 ft was reported in 13-year-old height data, between a control stand of *Pinus taeda* in Georgia, and a similar stand that was treated with a combination of competition control and fertilization. Kozlowski (1999) reports on a study that suggests a 40% increase in growth of *Pinus rigida, Pinus nigra and Picea abies* seedlings in cutover sites from similar seedlings growing on adjacent compacted skid trails. Kozlowski also reports that a study in Sweden suggested a 25% increase in height growth of *Picea abies* seedlings from similar seedlings growing on compacted soils. Burger et al. (1998) suggest a white pine site index (base age 25) of 45 ft for an average quality post-SMCRA reclaimed mine soil, and a site index of 70 ft for a properly reclaimed mine soil in Virginia.

Productivity increases associated with the site preparation and silvicultural treatments we consider on our particular site conditions are not well documented. Thus, a set of assumptions was made for this study, based somewhat on the aforementioned site productivity information, and keeping in mind the law of diminishing returns, i.e., a given site preparation intensity will tend to have decreasing positive growth effects when moving from poor quality sites to better quality sites.

Hardwoods:

- Medium intensity site preparation increases average site index values of site classes II, III, IV and V by 10 ft, and increases average site index value of site class I by 5 ft.
- High intensity site preparation increases average site index values of site classes III, IV and V by 20 ft, increases average site index value of site class II by 15 ft

and increases average site index value of site class I by 5 ft. *(90 ft at base age 50 years was set as a maximum site index for hardwoods. Hence an increase in average site index value of site class I of only 5 ft)*

White pine:

- Medium intensity site preparation increases average site index values of site classes I, II, III, IV and V by 12 ft (*no decreasing returns, as a site class I site starts out with a site index of 106 ft, and can still be significantly improved upon)*.
- High intensity site preparation increases average site index values of site classes II, III, IV and V by 24 ft, and increases average site index value of site class I by 18 ft (*124 ft at base age 50 years was set as a maximum site index for white pine)*.

These improvements, due to differing site preparation intensities, are primarily based on average site index increments from one site class to the next of 9.75 ft and 12 ft for mixed hardwoods and white pine, respectively. The improvements are ultimately reflected in the timber volumes produced at rotation.

III.8. Incentive schemes and policy design

In order to justify the conversion of land from one land use to another, from a purely economic standpoint, the LEV of the proposed land use must be at least equal to the LEV of the current land use. For the sake of this study, the LEV for all reclaimed land in its current state is assumed to be zero. This land has been abandoned, and hence, for the sake of this study, it is assumed that this land does not yield any monetary benefits. So too, any potential costs, such as management costs and property taxes associated with the abandoned land, are not taken into account in this study, as we anticipate that these costs will remain equal across all the proposed land use regimes. Therefore, in order to justify the conversion of these reclaimed mined lands from their current state to forests, the LEV of a given management regime should at least be equal to zero, thus suggesting no financial loss. However, some of the proposed management regimes may yield negative LEV values, which would suggest that such regimes are not economically feasible.

Such "economically infeasible management regimes" are not necessarily a lost cause. In order to render such a regime economically feasible, an incentive can be offered to the landowner in order to sway the associated LEV from a negative value to zero, or even a positive value. Therefore, the next step in this economic analysis was to determine the minimum payment for each proposed management regime that will yield non-negative LEVs for conversion of land use on a representative hectare. Incentive values were calculated for all negative LEVs in the subset of scenarios that assume a rotation age of 60 years for mixed hardwoods and 30 years for white pine, and that are in the 3.5% - 7.5% range of alternative rate of return. In order to predict a potential range of incentives, incentive values were also calculated for each of the high, base case and low LEV scenarios for both mixed hardwood and white pine. An incentive payment could take on many forms, of which three commonly used subsidy schemes are explored in this study, namely:

1. Lump sum payment, paid at the time of planting – this payment will equate to a one time payment made at the time of planting, in order to render the given scenario economically feasible. This incentive is simply calculated as being the value that would balance the loss represented by any negative LEV:

$$\boxed{\text{Incentive} = -\text{(LEV)}} \qquad \text{for all LEV} < 0$$

This lump sum payment will also be translated into a set of equal annual payments. In order to translate this lump sum payment into a set of equal annual payments, the following calculation was used:

$$\boxed{\text{Annual payment} = -\text{(LEV)} \times i} \qquad \text{for all LEV} < 0$$

2. Payment based on revenue received at harvest – this payment will equate to the increase in revenue required to render the given regime economically feasible. The lump sum subsidy to be paid at harvest is calculated by firstly solving the following equation for K, and then multiplying K by the revenue at harvest:

$$\boxed{[\sum_{t=0}^{T} R_t(1+K)/(1+i)^t - \sum_{t=0}^{T} C_t/(1+i)^t]/(1-(1+i)^{-T}) = 0}$$

Where:

K = proportional increase in revenue received at harvest

3. Payment based on carbon volume present each year – this payment will equate to an annual payment per unit carbon volume present, required to render the given scenario economically feasible. In other words, we will calculate the necessary value of carbon to render a given scenario economically feasible. The payment per unit carbon volume is calculated by solving the following equation for Z:

$$\boxed{[\sum_{t=0}^{T} R_t/(1+i)^t - \sum_{t=0}^{T} C_t/(1+i)^t + Z\sum_{t=1}^{T} X_t/(1+i)^t]/(1-(1+i)^{-T}) = 0}$$

Where:

Z = annual per unit carbon volume payment ($/ton)

X_t *= carbon volume present at end of year t (tons/ha)*

Conversions from timber volume to total carbon content (X_t) were based on the conversion factors used by van Kooten et al. (2000):

- multiply the merchantable stand volume by an expansion factor (=1.57) to obtain total above-ground biomass (G):

  hardwoods and softwoods: $G = 1.57V$

  Where V = total stand volume (m^3/ha)

- root biomass (R) is related to above-ground biomass as follows, with both measured in tons per ha:

  hardwoods: $R = 1.4319G^{0.639}$

  softwoods: $R = 0.2317G$

- total biomass (m^3/ha) = G + R
- average carbon content in timber is given by:

  hardwoods: 0.187 tons carbon per m^3

  softwoods: 0.207 tons carbon per m^3

- total carbon content (tons/ha) is given by:

  hardwoods: $0.187(G+R)$

  softwoods: $0.207(G+R)$

For the sake of our carbon payment calculations, it is assumed that all harvested timber is converted into permanent timber products, and hence, carbon is permanently sequestered. The carbon payments calculated for the purposes of this study are based only on tree carbon volumes, and do not take into account soil carbon. Soil carbon data from the study by Rodrigue (2001) was analyzed, but no statistically significant relationship was found to exist between soil carbon volumes and stand age. According to Rodrigue

(2001), soil carbon volumes on mined sites can amount to approximately 20% of the total ecosystem carbon volumes. Hence, if soil carbon volumes were to be incorporated in the carbon subsidy calculations, annual per ton carbon payments would decrease somewhat.

The economic implications of these various incentive schemes, and the implications that each one has on the landowner's decision-making process are subsequently analyzed. This part of the economic analysis is ultimately aimed at helping develop a framework for evaluating the best types of policies that the government or other agencies might use to encourage the establishment of forests on reclaimed mined lands.

III.9. Anticipated results

Through this study, I hope to develop a framework for understanding the economic implications of converting reclaimed mined lands to forests, and for developing incentive schemes to encourage this land-use conversion. Furthermore, the profitability of a range of land-use conversion scenarios will be estimated for various silvicultural schemes, under a variety of product prices and alternative rates of return. Ranges of incentive levels, required to render land-use conversions profitable for landowners, will also be estimated for the three proposed types of incentives.

The primary importance of this study will lie in its ability to assist landowners in their decision to convert their mined lands to forest plantations. It will also shed some light for policy-makers on the feasibility of encouraging these land-use conversions through various incentive schemes. The primary limitation to this study is the limited range of case study data on which our economic analysis will be based, and the lack of case study data to which our results can be compared.

CHAPTER IV – RESULTS AND DISCUSSION

IV.1. Introduction

Chapter III dealt with the framework developed for this study, to calculate some measure (LEV) of the economic implications of converting reclaimed mined lands to forests, under various silvicultural regimes, and the incentives necessary to render these regimes economically feasible for landowners. This chapter will present a spectrum of estimated land expectation values and incentive values, and the trends displayed by both.

In evaluating the economic feasibility of converting reclaimed mined lands to forests, a broad spectrum of scenarios has been investigated, based on site class, site preparation intensity, alternative rate of return, rotation length and product prices. A few general trends run throughout a large portion of the results, even though a number of the proposed scenarios differ subtly from one another. A subset of scenarios are discussed to highlight the general trends. As a reference point, the base case scenario will be the land-use conversion scenario based on average site conditions and input factors. Hence, the base case scenario is that based on a rotation of 60 years and 30 years for mixed hardwoods and white pine respectively, an alternative rate of return of 5%, a site class III site, and medium site preparation intensity. Discussion of results will also be limited to the 3.5% - 7.5% range of alternative rate of return. This range of alternative rates of return covers the general trends in the results. Land expectation value and incentive results will be discussed in detail for the set of low product prices, and will be more briefly summarized for the set of high product prices. Full results are presented in Appendix A.

IV.2. Growth and yield

The volume of sawtimber and pulpwood present in a forest stand at harvest age ultimately determines the amount of revenue that can be earned from sawtimber and pulpwood sales. The value of sales in turn partly determines the land expectation value (LEV) of a given reforestation regime. Hence, knowledge of the volumes of sawtimber and pulpwood produced by a given forest stand over a range of rotation ages is the first step in calculating LEVs and incentive values for this study. So too, knowledge of the volume of carbon present in a forest stand at a given age is necessary in calculating incentive values based on forest stand carbon content.

IV.2.1. Hardwoods

The mixed hardwood growth and yield function estimated for this study is presented graphically in Figure 4 for units of m^3/ha and tons/ha, for a site class III site under low intensity site preparation. Results suggest that the maximum periodic annual increment (PAI) for this forest stand is occurring between 10 and 20 years of age. Hereafter, the marginal rate of timber production decreases. Stand volumes estimated with this yield equation are comparable to the 46-year-old stand volumes measured by Zeleznik and Skousen (1996) on reclaimed mines in Ohio.

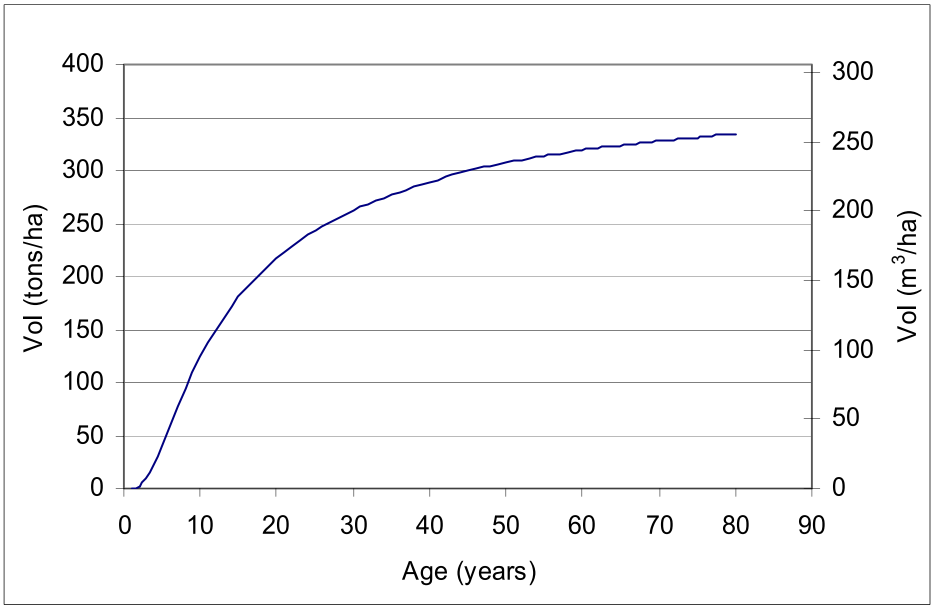

Figure 4 – Growth and yield of mixed hardwoods (site class III, low intensity site preparation)

Figure 5 – Mixed hardwood forest stand carbon volume by age (site class III, low intensity site preparation) – based on van Kooten et al. (2000) carbon conversion factors

Figure 5 shows carbon volume content of a mixed hardwood forest stand at a given age, for a site class III site under low intensity site preparation. These carbon volumes are based on the mixed hardwood growth and yield equation estimated for this study and a series of conversion factors (discussed in chapter III) taken from the study by van Kooten et al. (2000). These carbon volumes are consistent with those volumes estimated by Ravindrath and Somashekhar (1995) for the revegetation of degraded lands to hardwood plantations, and are within the range of carbon volumes estimated by Xu (1995) over a range of afforestation management scenarios.

IV.2.2. White pine

The white pine growth and yield function estimated for this study is presented graphically in Figure 6 for units of m^3/ha and tons/ha, for a site class III site under low intensity site preparation. Results suggest that the maximum periodic annual increment (PAI) for this forest stand is occurring between 25 and 35 years of age. Stand volumes estimated with this yield equation are similar to the white pine stand volumes reported by Davidson (1981) for plantings on mined lands in Pennyslvania.

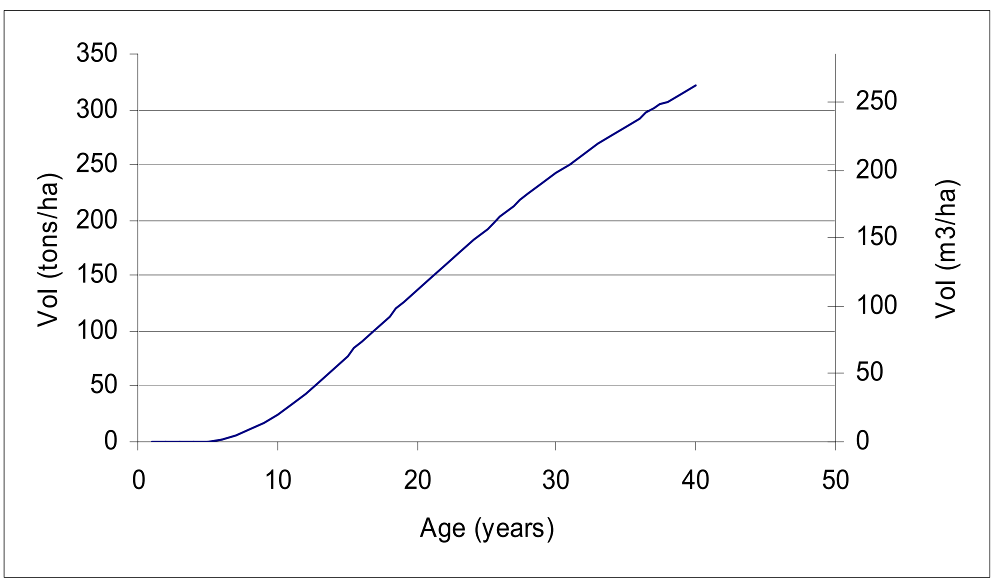

Figure 6 - Growth and yield of white pine (site class III, low intensity site preparation)

Figure 7 shows carbon volume content of a white pine forest stand at a given age, for a site class III site under low intensity site preparation. These carbon volumes are based on the white pine growth and yield equation estimated for this study and a series of conversion factors taken from the study by van Kooten, et al (2000). These carbon volumes are consistent with those volumes estimated by Ravindrath and Somashekhar (1995) for the revegetation of degraded lands to softwood plantations, and are within the range of carbon volumes estimated by Xu (1995) over a range of afforestation management scenarios.

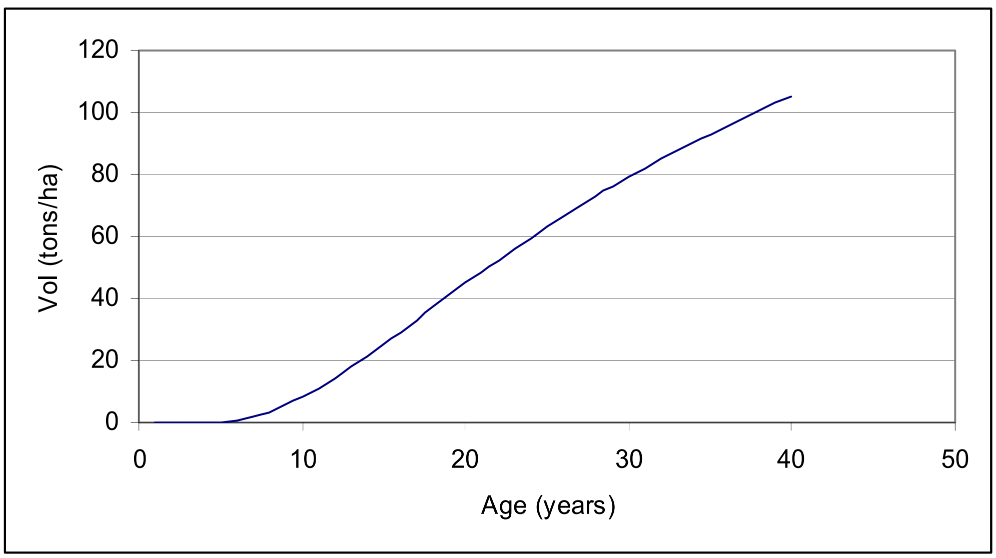

Figure 7 – White pine forest stand carbon volume by age (site class III, low intensity site preparation) - based on van Kooten et al. (2000) carbon conversion factors

IV. 3. Low price scenarios

All results presented and discussed in the following sections are based on the low set of product prices, as explained in chapter III. This set of low prices comprised 1st quarter 2003 Timber Mart-South standing timber average prices for mixed hardwoods and pine in Virginia.

IV.3.1. Land expectation values (LEV)

In the following sections, the economic feasibility of converting reclaimed mined lands to mixed hardwood and white pine forests will be discussed in terms of LEVs. More specifically, the effects of the following factors on LEV will be analyzed: rotation age, site class, site preparation intensity and alternative rate of return.

IV.3.1.A. Effect of rotation age on LEV

An investment made in a land-use conversion to forestry is a long-term investment. A rotation length of 20 years versus a rotation length of 80 years has significant implications in terms of factors such as the time value of money and alternative investments, stand growth and volume, levels of risk, and markets. Hence, deciding how long to grow a stand of trees is one of the first management decisions a landowner has to make in an effort to optimize his/her investment.

Hardwoods

Figures 8 - 10 show mixed hardwood LEV trends for each site class, over a range of rotation ages. These trends remain relatively constant throughout all three site preparation intensities.

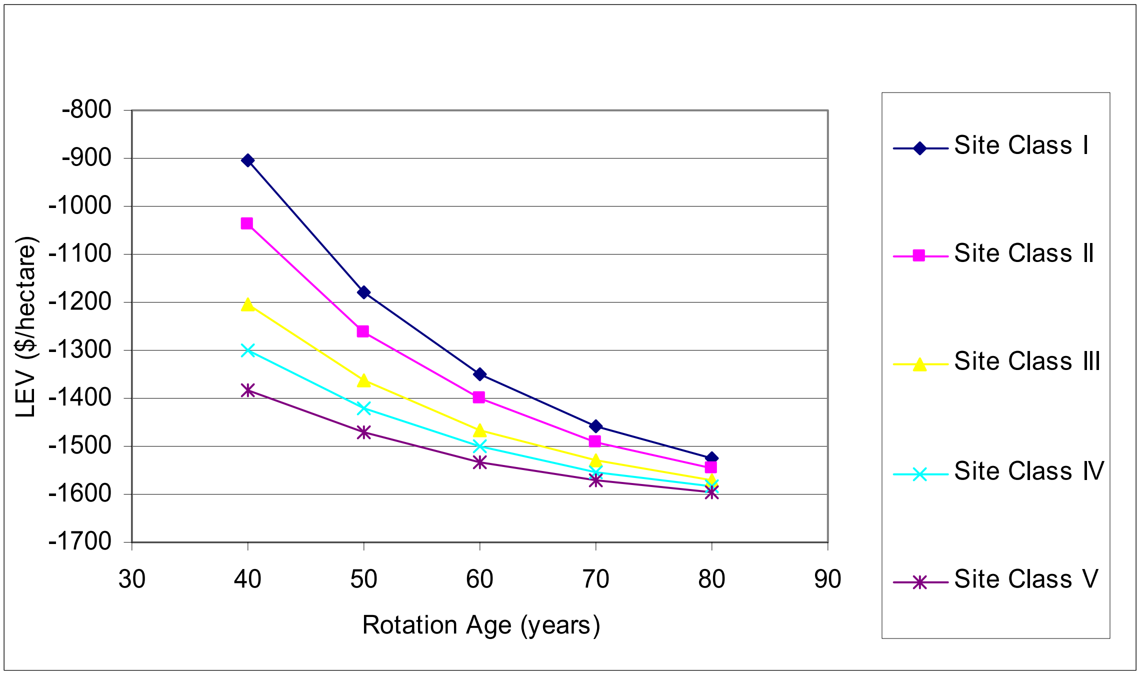

Figure 8 –Mixed hardwood LEV by rotation for various site classes (low intensity site preparation, low prices, 5% ARR)

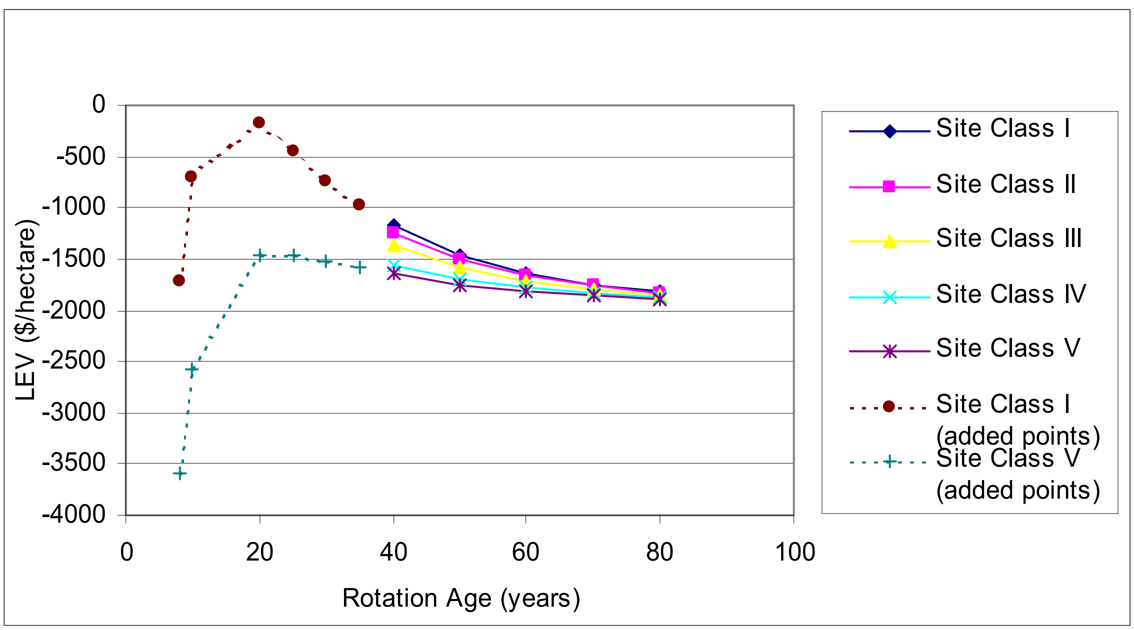

Figure 9 –Mixed hardwood LEV by rotation for various site classes – projected back to 8 years (medium intensity site preparation, low prices, 5% ARR)

Note that for the high intensity site preparation scenario (Figure 10), site classes I and II yield equivalent LEV values. This is due to both of these site classes having the same site index value under high intensity site preparation, as was discussed in chapter III.

The initial results did not yield any obvious maximum LEV or optimal rotation age for mixed hardwoods within the rotation age range of 40-80 years. Subsequently, additional data points were plotted for the medium intensity site preparation scenario (Figure 9), as LEVs were projected back to a rotation age of 8 years for site classes I and V. For both site classes I and V, the maximum LEV occurred at a rotation age of approximately 20 years, thus suggesting that a rotation age of 20 years would be optimal, if maximizing LEV were the primary objective, based solely on total standing timber volume and value, and not product volumes and values.

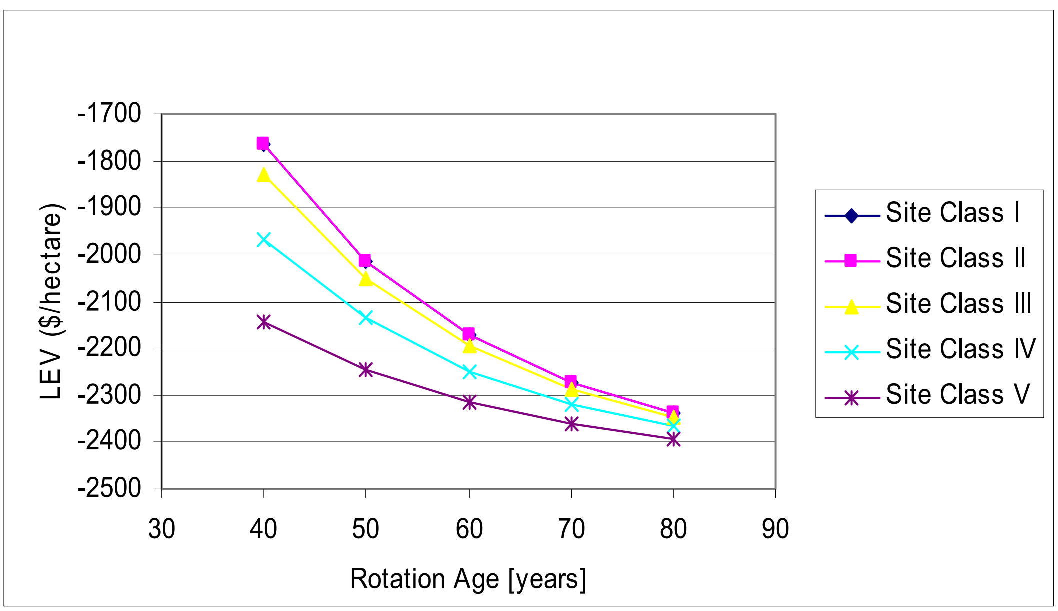

Figure 10 –Mixed hardwood LEV by rotation for various site classes (high intensity site preparation, low prices, 5% ARR)

A rotation age of 20 years for mixed hardwoods, however, is somewhat unrealistic when growing sawtimber is one of the primary objectives. Hardwood sawtimber would not yet be mature by this age. It is suspected that the reason for this short "optimal" rotation was a failure to take into account the fact that product ratios vary with rotation age i.e., a young forest stand will tend to comprise a high percentage of pulpwood and a low percentage of sawtimber, whereas a mature forest stand will tend to comprise a low percentage of pulpwood and a high percentage of sawtimber. Due to the higher value of sawtimber over pulpwood, one would expect the maximum LEV to occur at a higher rotation age when taking into account varying product ratios and values with age, as opposed to the scenario where LEV is maximized, based solely on total standing timber volume. This suspected limitation was somewhat verified by simulating additional data points, by estimating varying product ratios with rotation age (Figure 11). A site of average quality (site class III) was used, and a case was simulated for both a low price and a high price scenario. The low price scenario yielded a maximum LEV at rotation age 50 years, and the high price scenario yielded a maximum LEV at rotation age 40 years. These rotation ages are more acceptable for hardwood stands grown primarily for sawtimber. Hence, the failure to account for varying product ratios with rotation age is recognized as a limitation to this study, and is something that can be improved upon in future research.

From hence forth, mixed hardwood results and general trend discussions will be primarily based on scenarios utilizing an average rotation age of 60 years.

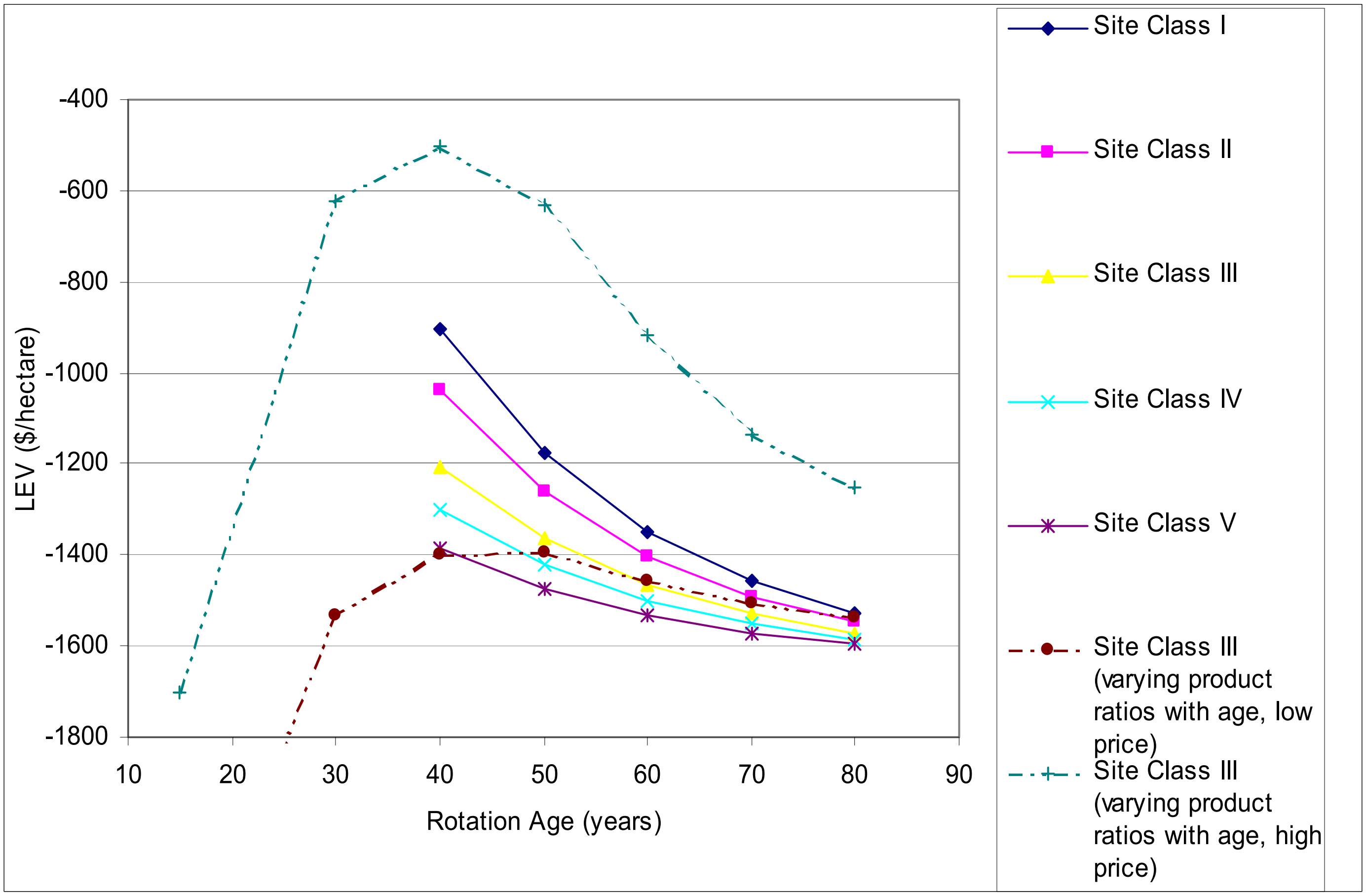

Figure 11 – Mixed hardwood LEV by rotation for various site classes – product ratios varied with rotation age (low intensity site preparation, low prices, 5% ARR)

White pine

Figures 12 - 14 show white pine LEV trends for each site class, over a range of rotation ages. These trends remain relatively constant throughout all three site preparation intensities. The results suggest that, depending on the quality of the site, the optimal white pine rotation falls somewhere in the range of 25-35 years. A rotation age of 25 years would maximize LEV on site classes I and II. Similarly, a rotation age of 30 years would maximize LEV on site class III, and a rotation age of 35 years would maximize LEV on site classes IV and V.

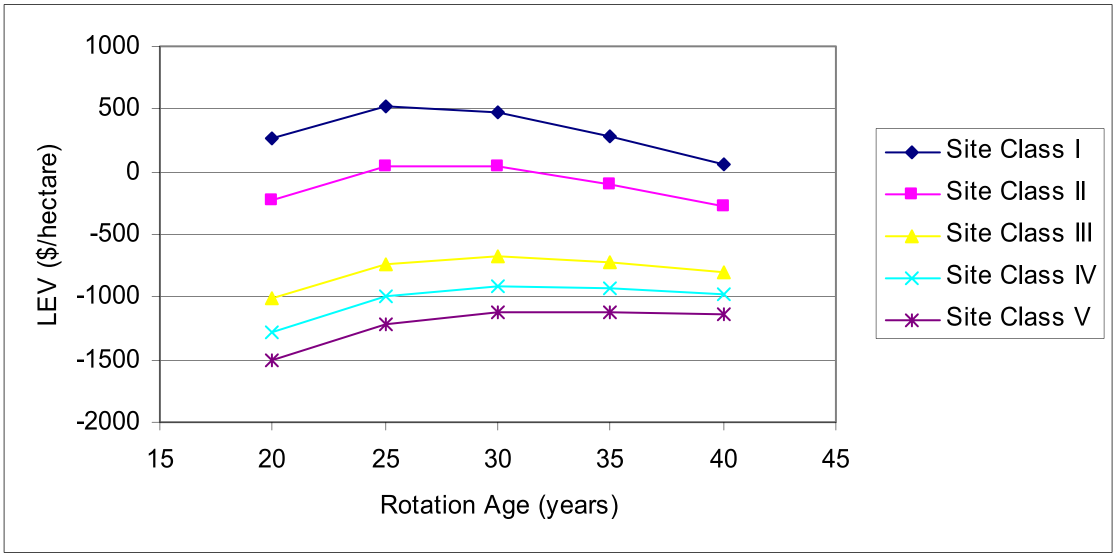

Figure 12 – White pine LEV by rotation for various site classes (low intensity site preparation, low prices, 5% ARR)

The failure to vary product ratios with rotation age was not evident in the white pine results. This is primarily due to the rapid rate of growth that white pine trees exhibit, which results in shorter rotations used in growing white pine, as opposed to longer rotations used in growing mixed hardwoods. These shorter rotations result in a greater percentage of product class overlap with changing rotation age, and hence the failure to distinguish between product classes with changing rotation ages should not change the results significantly. However, this is something that should be taken into consideration in future research, as it will aid in refining the results.

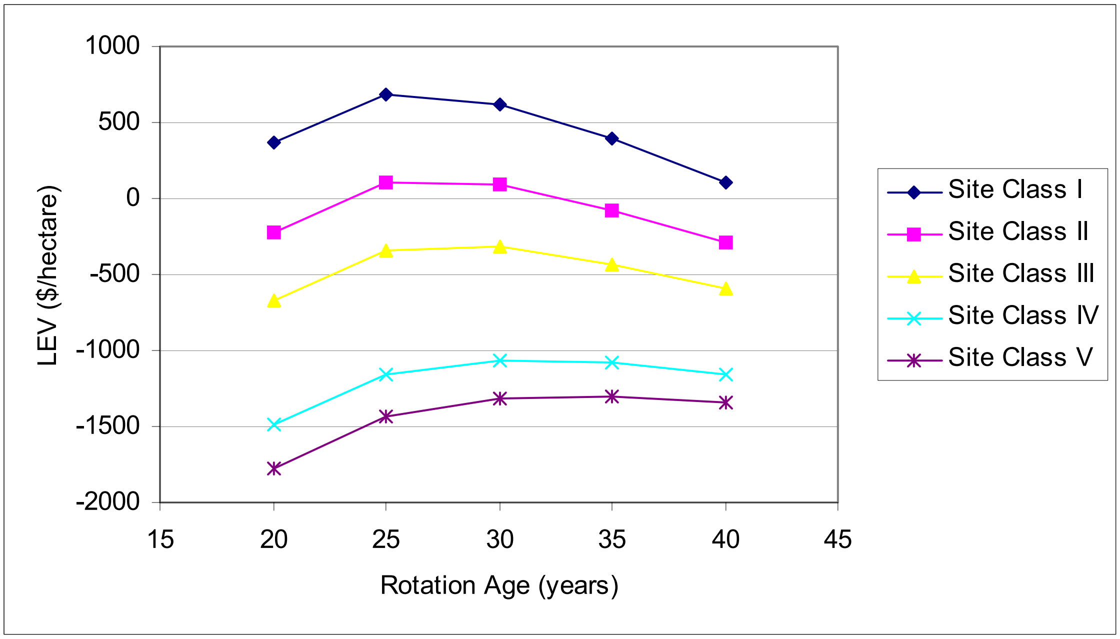

Figure 13 - White pine LEV by rotation for various site classes (medium intensity site preparation, low prices, 5% ARR)

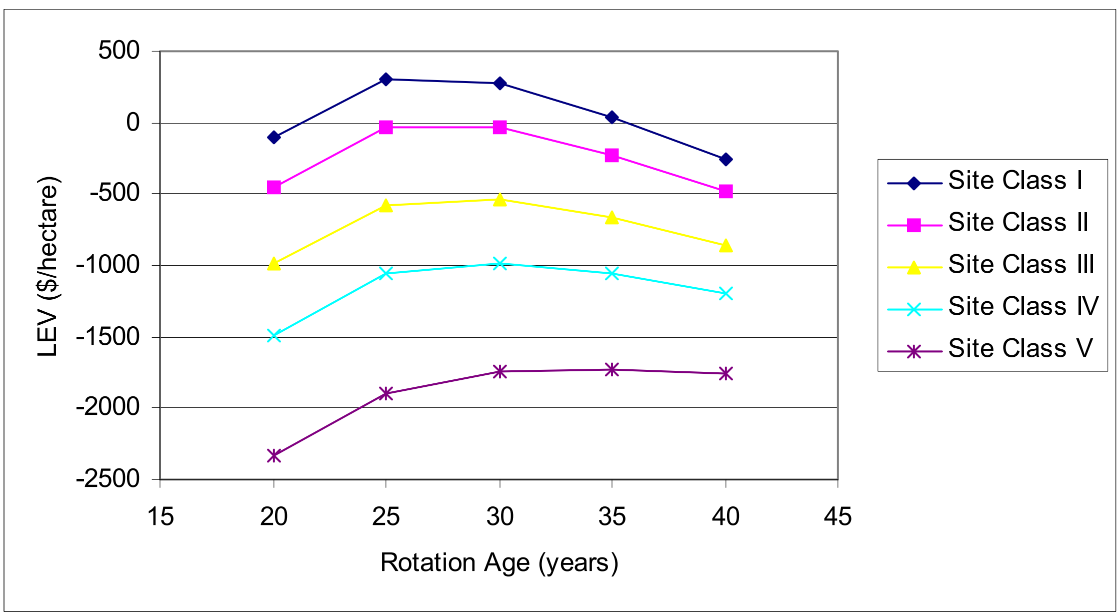

Figure 14 - White pine LEV by rotation for various site classes (high intensity site preparation, low prices, 5% ARR)

It is clear that the optimal rotation age for a given site preparation intensity does depend on site class. It would seem that, based on maximizing LEV, the optimal white pine rotation is shorter on better sites, and longer on poorer sites. From hence forth, white pine results and general trend discussions will be primarily based on scenarios utilizing an average rotation age of 30 years.

IV.3.1.B. Effect of site class on LEV

The innate ability of a given site to support the growth and development of a forest stand is a valuable attribute that is exploited in forestry. In general, the higher the productive potential of a site, the better the quality of the site. For this study, site quality is ranked on a scale of I – V, with site class I being the best quality sites, and site class V being the poorest quality sites. The productive potential of a site is directly related to the volume of sawtimber and pulpwood present at harvest, which is directly related to the LEV of a given forestry investment. Therefore we analyze the effect of site class on LEV.

Hardwoods

Of course, LEVs increase when moving from poor quality sites (site class V) to good quality sites (site class I) (Table 24). This trend is also illustrated in Figures 15 - 17.

Table 24 – Mixed hardwood LEVs - $/ha - (60 year rotation, 5% ARR, low prices)

	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	-1532.35	-1814.41	-2316.93
4	-1501.11	-1778.30	-2248.79
3	-1465.01	-1710.16	-2196.42
2	-1401.70	-1663.37	-2173.24
1	-1350.08	-1634.61	-2173.24

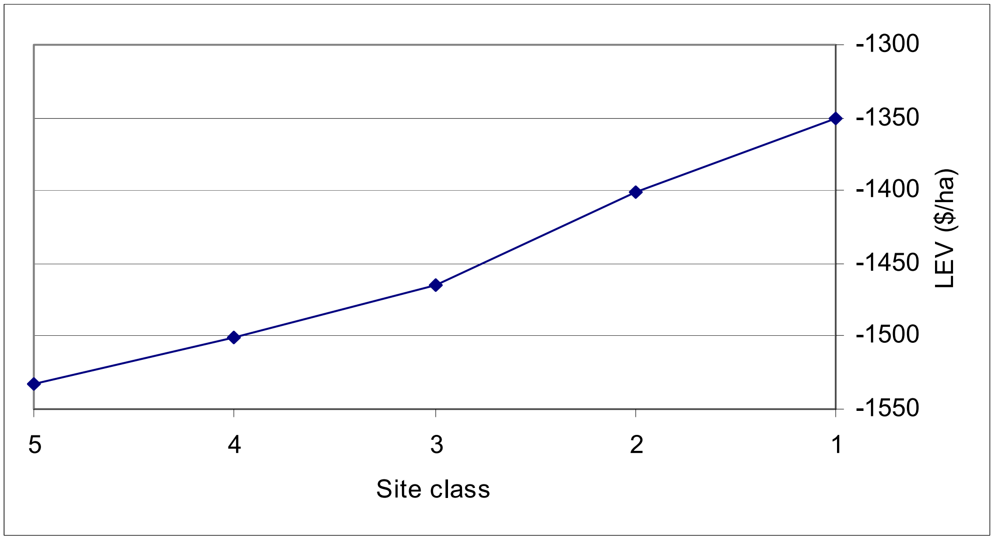

Figure 15 – General trend for mixed hardwood LEV over range of site classes (low intensity site preparation, 60 year rotation, low prices, 5% ARR)

According to results, for a mixed hardwood plantation with low intensity site preparation, a 60 year rotation, a 5% ARR, and for the low price set, LEV increases at a rate of $31.24/ha when moving from site class V to site class IV. Similarly, LEV increases at a rate of $36.10/ha when moving from site class IV to site class III, increases at a rate of $63.31/ha when moving from site class III to site class II, and increases at a rate of $51.62/ha when moving from site class II to site class I. Under low intensity site preparation (Figure 15), LEV tends to increase sharply from site class III to site class II. This increase in LEV is a result of the sawtimber to pulpwood ratio increasing from 66.7% : 33.4% to 75% : 25%. The higher proportion of the more valued sawtimber results in the sharp increase in LEV.

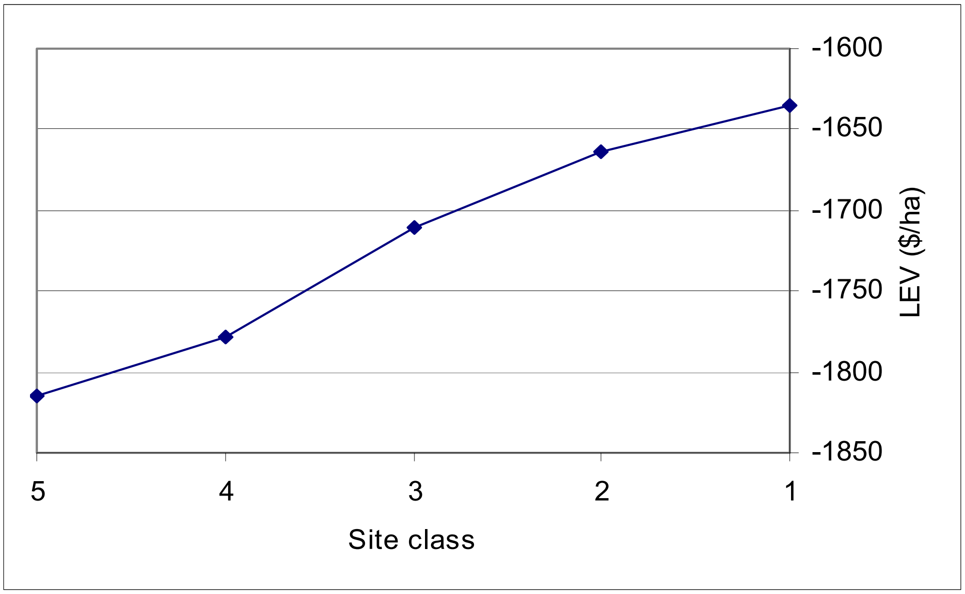

Figure 16 – General trend for mixed hardwood LEV over range of site classes (medium intensity site preparation, 60 year rotation, low prices, 5% ARR)

Based on the assumption, made in chapter III, of increasing site index with increasing intensity of site preparation, under medium intensity site preparation, a site that was a site class III site before site preparation becomes a site class II site as a result of site preparation, and a site that was a site class IV site becomes a site class III site as a result of site preparation. Thus, due to the changing product ratios when moving from site class III to site class II under low intensity site preparation, under medium intensity site preparation, LEV tends to increase sharply from site class IV to site class III (Figure 16). According to results, for a mixed hardwood plantation with medium intensity site preparation, a 60 year rotation, a 5% ARR, and for the low price set, LEV increases at a rate of $36.11/ha when moving from site class V to site class IV. Similarly, LEV increases at a rate of $68.14/ha when moving from site class IV to site class III, increases at a rate of $46.79/ha when moving from site class III to site class II, and increases at a rate of $28.76/ha when moving from site class II to site class I.

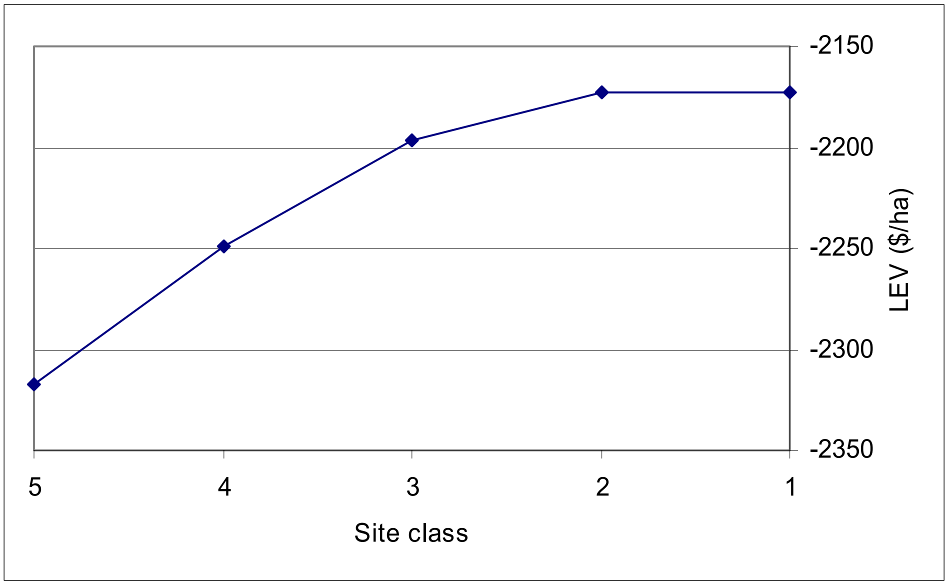

Figure 17 – General trend for mixed hardwood LEV over range of site classes (high intensity site preparation, 60 year rotation, low prices, 5% ARR)

Similarly, under high intensity site preparation, a site that was a site class IV site before site preparation becomes a site class II site as a result of site preparation, and a site that was a site class V site becomes a site class III site as a result of site preparation. Therefore, under high intensity site preparation, LEV tends to increase sharply from site class V to site class IV (Figure 17). According to results, for a mixed hardwood plantation with high intensity site preparation, a 60 year rotation, a 5% ARR, and for the low price set, LEV increases at a rate of $68.14/ha when moving from site class V to site class IV. Similarly, LEV increases at a rate of $52.37/ha when moving from site class IV to site class III, increases at a rate of $23.18ha when moving from site class III to site class II, and does not increase when moving from site class II to site class I.

White pine

Similar to the mixed hardwoods, under low intensity site preparation, LEV tends to increase sharply from site class III to site class II (Table 25). This trend is illustrated in Figure 18. This increase is a result of the sawtimber to pulpwood ratio increasing from 50% : 50% to 75% : 25%. The higher proportion of the more valued sawtimber results in the sharp increase in LEV.

Table 25 – White pine LEVs - $/ha – (30 year rotation, 5% ARR, low prices)

	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	-1125.97	-1318.31	-1747.07
4	-914.67	-1062.16	-979.31
3	-676.38	-316.06	-532.05
2	36.19	90.56	-39.10
1	476.35	624.15	268.78

According to results, for a white pine plantation with low intensity site preparation, a 30 year rotation, a 5% ARR, and for the low price set, LEV increases at a rate of $211.30/ha when moving from site class V to site class IV. Similarly, LEV increases at a rate of $238.29/ha when moving from site class IV to site class III, increases at a rate of $712.57/ha when moving from site class III to site class II, and increases at a rate of $440.16/ha when moving from site class II to site class I.

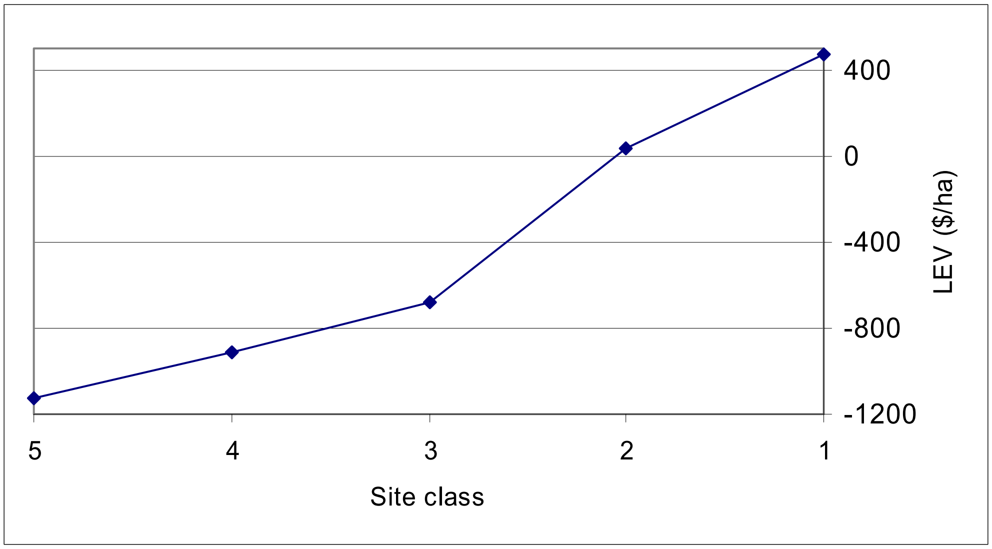

Figure 18 – General trend for white pine LEV over range of site classes (low intensity site preparation, 30 year rotation, low prices, 5% ARR)

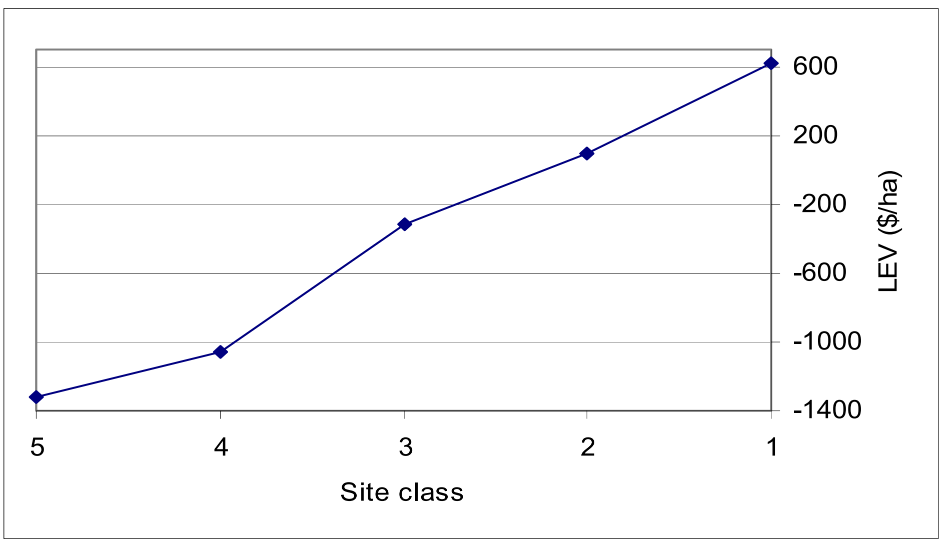

Figure 19 – General trend for white pine LEV over range of site classes (medium intensity site preparation, 30 year rotation, low prices, 5% ARR)

As with the mixed hardwoods, based on the assumption, made in chapter III, of increasing site index with increasing intensity of site preparation under medium intensity site preparation, a site that was a site class III site before site preparation becomes a site class II site as a result of site preparation and a site that was a site class IV site becomes a site class III site as a result of site preparation. Thus, due to the changing product ratios when moving from site class III to site class II, under medium intensity site preparation LEV tends to increase sharply from site class IV to site class III (Figure 19). According to results, for a white pine plantation with medium intensity site preparation, a 30 year rotation, a 5% ARR, and for the low price set, LEV increases at a rate of $256.15/ha when moving from site class V to site class IV. Similarly, LEV increases at a rate of $746.10/ha when moving from site class IV to site class III, increases at a rate of $406.62/ha when moving from site class III to site class II, and increases at a rate of $533.59/ha when moving from site class II to site class I.

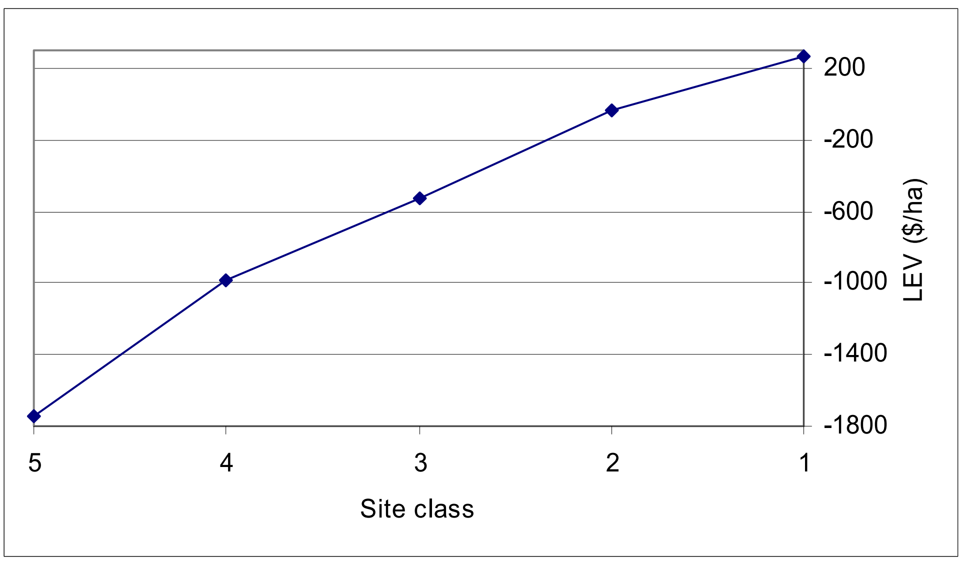

Figure 20 – General trend for white pine LEV over range of site classes (high intensity site preparation, 30 year rotation, low prices, 5% ARR)

Similarly, under high intensity site preparation, a site that was a site class IV site before site preparation becomes a site class II site as a result of site preparation and a site that was a site class V site becomes a site class III site as a result of site preparation. Therefore, under high intensity site preparation, LEV tends to increase sharply from site class V to site class IV (Figure 20). According to results, for a white pine plantation with high intensity site preparation, a 30 year rotation, a 5% ARR, and for the low price set, LEV increases at a rate of $767.76/ha when moving from site class V to site class IV. Similarly, LEV increases at a rate of $447.26/ha when moving from site class IV to site class III, increases at a rate of $492.95/ha when moving from site class III to site class II, and increases at a rate of $307.88/ha when moving from site class II to site class I.

IV.3.1.C. Effect of site preparation intensity on LEV

Having discussed the effect of site class on LEV, it is important to note that the productive capacity of a forest site is also something that can be enhanced through various site preparation techniques. However, site preparation does come at a cost. This cost increases with increasing intensity of site preparation. Hence, it is necessary to determine whether the artificially enhanced productive capacity of a site is worth the cost of preparing the site.

Hardwoods

According to results, the intensity with which a site is prepared does influence the LEV of mixed hardwoods plantations. For all site classes, mixed hardwood LEV tends to decrease with increasing site preparation intensity (Figure 21). This trend is consistent throughout all the proposed mixed hardwood scenarios, which are based on the low price set. This trend would suggest that increasing site preparation beyond the low intensity level is not an economically beneficial option.

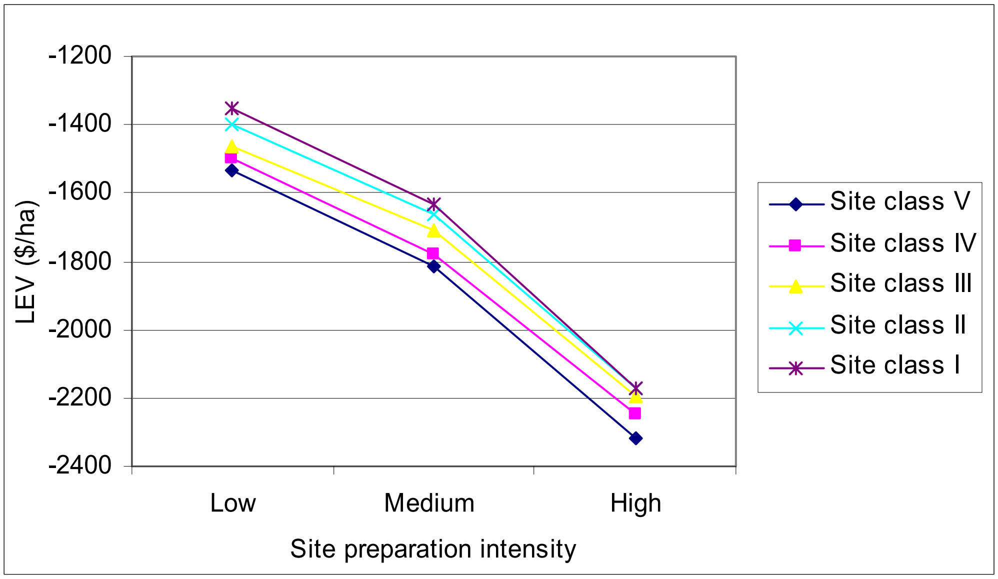

Figure 21 – Effect of site preparation on mixed hardwood LEV, over range of site classes (60 year rotation, low prices, 5% ARR)

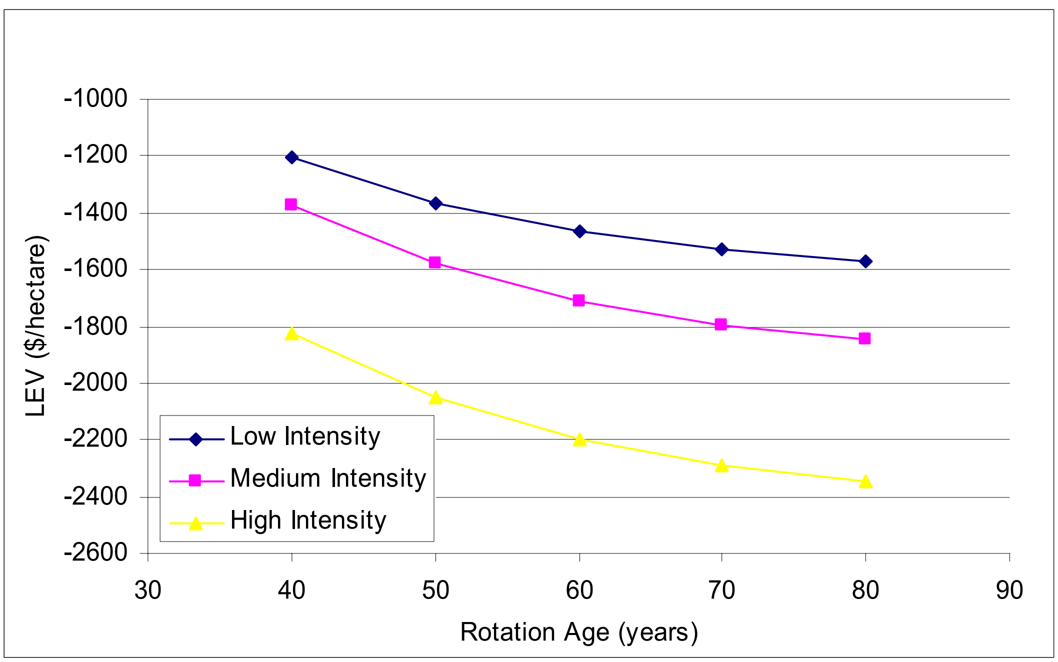

Figure 22 – Effect of site preparation on mixed hardwood LEV, over range of rotation ages (site class III, low prices, 5% ARR)

In other words, the increased costs of site preparation, associated with increasing site preparation intensity, outweigh the growth and yield benefits associated with the improved site quality. This trend is further verified in Figure 22, which clearly shows that, for any given rotation age, regimes based upon a low site preparation intensity yield the highest LEVs. Hence, the results from our study would suggest that minimal site preparation would be advisable for mixed hardwoods on reclaimed mined lands.

White pine

The results also show that the intensity with which a site is prepared also influences the LEV of white pine plantations. The white pine results, however, do not exhibit as clear and consistent a trend as the mixed hardwood results. Figure 23 shows trends based on a rotation age of 30 years, an alternative rate of return of 5% and low product prices. Results for this subset of scenarios suggest that LEV is maximized on site classes I, II and III under medium intensity site preparation. On these good quality sites, it would seem economically beneficial to implement a medium intensity site preparation regime. In other words, the financial benefits received, due to the improved site quality as a result of ripping, outweigh the costs of increasing the site preparation intensity from low to medium. This distinct increase in LEV for site classes I, II and III when moving from low to medium site preparation intensity can, in part, be attributed to the substantial increase in sawtimber to pulpwood ratio when moving from a site class IV to a site class III site under medium intensity site preparation.

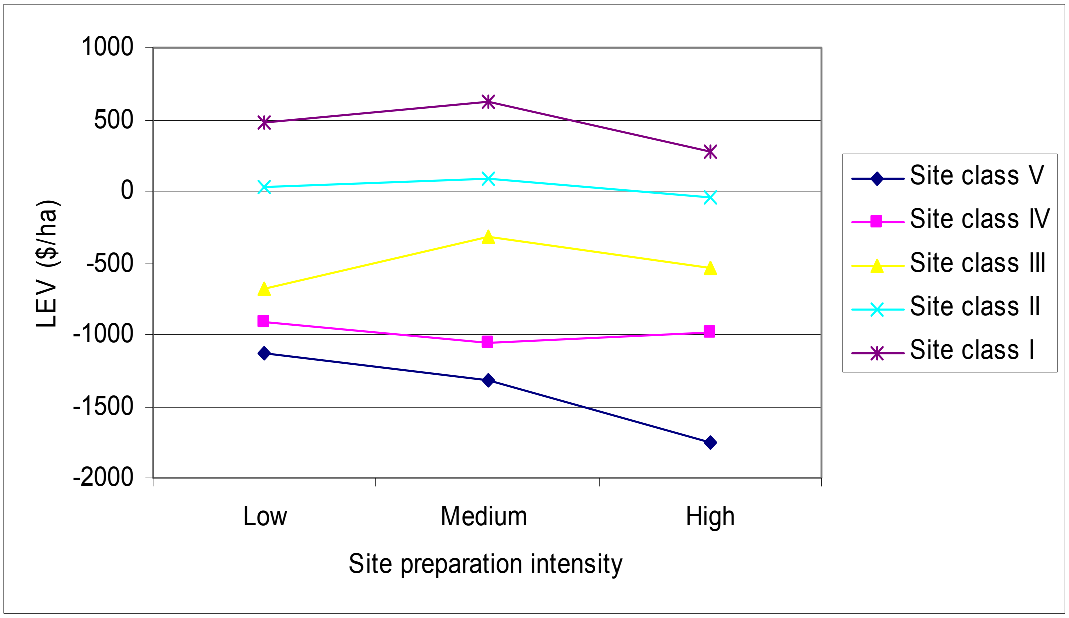

Figure 23 – Effect of site preparation on white pine LEV, over range of site classes (30 year rotation, low prices, 5% ARR)

Site classes IV and V show a distinctly different trend. According to results, LEV is maximized under low intensity site preparation on these poorer quality sites. This decrease in LEV when moving from a low intensity to a medium intensity site preparation regime suggests that the increased costs associated with this increased site preparation intensity outweigh the benefits of the associated improvement in site quality on these poorer quality sites. The apparent increase in LEV when moving from medium to high site preparation intensity on site class IV can, in part, be attributed to the substantial increase in sawtimber to pulpwood ratio when moving from a site class V to a site class IV site, under high intensity site preparation. This increase in LEV, as a result of changing product ratios, however, still does not outweigh the increase in costs associated with increasing the site preparation intensity from low to high. The product ratios produced on site class V remain constant under all site preparation intensities, which is, in part the reason for the trend of decreasing LEV with increasing site preparation intensity on site class V.

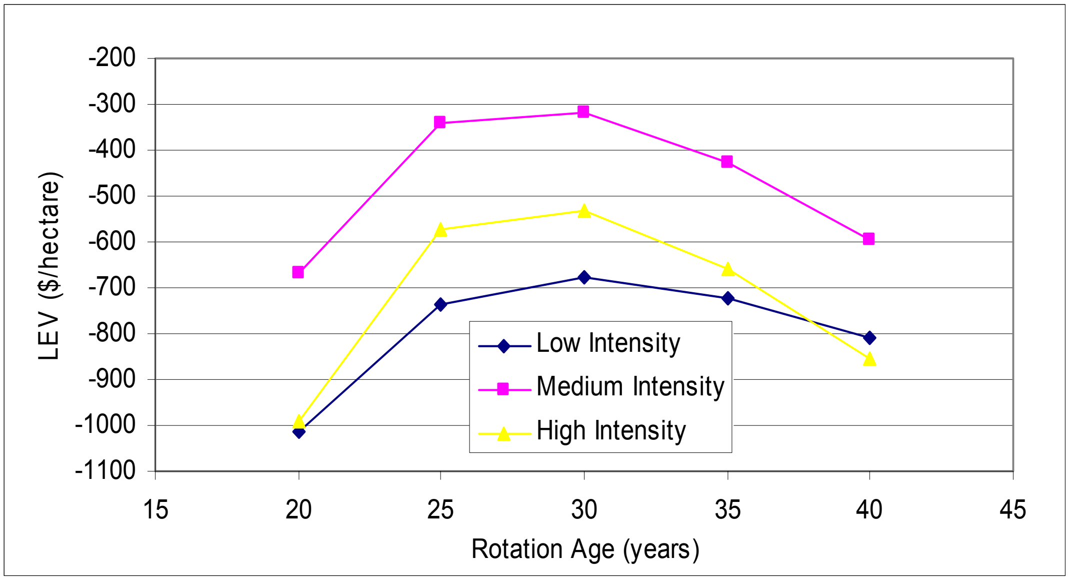

Figure 24 – Effect of site preparation on white pine LEV, over range of rotation ages (site class III, low prices, 5% ARR)

Figure 24 illustrates the effect that site preparation intensity has on white pine LEV over a range of rotation ages, on a site class III site, and for a 5% alternative rate of return. It is clear that, for this subset of scenarios, white pine LEV is maximized for all proposed rotation ages under medium intensity site preparation. Low intensity site preparation appears to yield the lowest LEVs for rotation ages between 20 years and approximately 38 years, which in itself suggests that some form of site preparation, beyond the initial low intensity weed control, is economically profitable within this rotation age range. Figure 25 shows that, in comparison to the 5% ARR scenario, a lower alternative rate of return tends to warrant a higher intensity of site preparation. At the 3.5% ARR level, there is not much difference between the white pine LEVs yielded under medium and high intensity site preparation, particularly in the 25 – 40 year range of rotation ages.

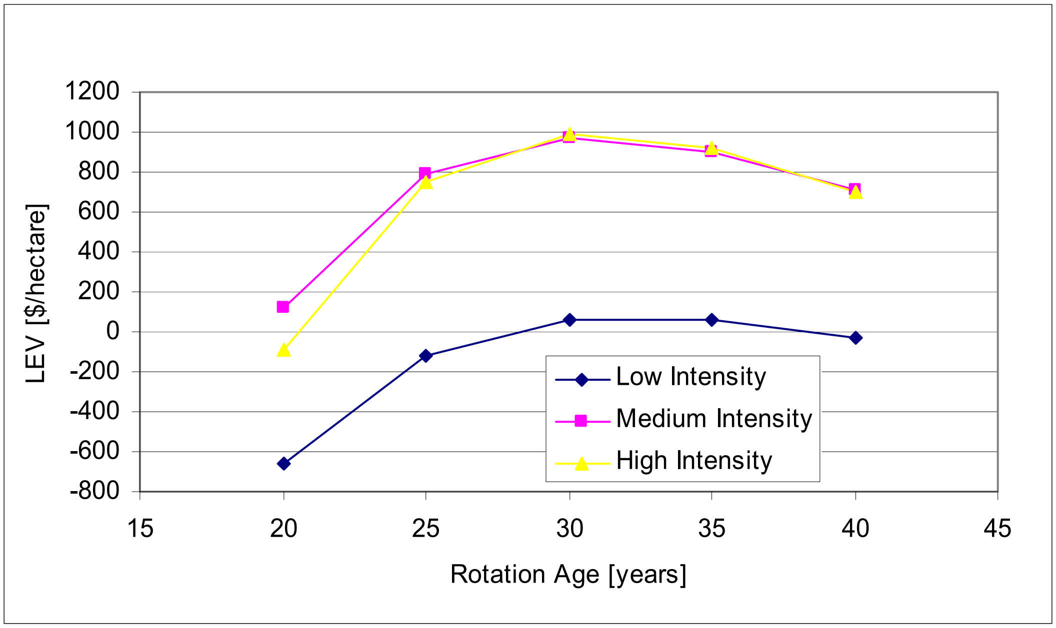

Figure 25 - Effect of site preparation on white pine LEV, over range of rotation ages (site class III, low prices, 3.5% ARR)

So too, Figure 26 illustrates that, in comparison to the 5% ARR scenario, a higher alternative rate of return tends to warrant a lower intensity of site preparation. At the 7.5% ARR level, white pine LEV is maximized under medium intensity site preparation for rotation ages 20 to approximately 28 years. For any rotation longer than 28 years, however, white pine LEV appears to be maximized under low intensity site preparation.

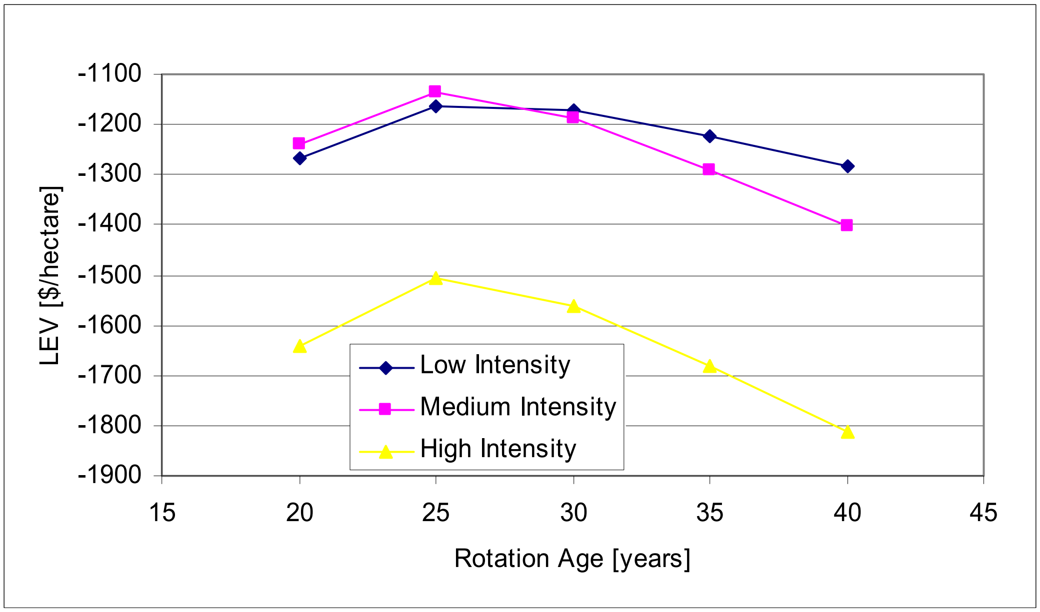

Figure 26 - Effect of site preparation on white pine LEV, over range of rotation ages (site class III, low prices, 7.5% ARR)

IV.3.1.D. Effect of alternative rate of return on LEV

When making the decision to remove money from one investment, in order to invest in another, or when analyzing one's investment options in general, the rate at which one could be earning on an alternative investment is of importance. It would seem probable that, given the decision to invest in forestry, one would use money from the current investment that is earning the lowest alternative rate of return, in order to establish the forest.

Hardwoods

Figure 27 shows that, for a given site preparation intensity, mixed hardwood LEVs tend to decrease with increasing alternative rate of return. Also, the trend of decreasing LEV with increasing intensity of site preparation remains consistent over the entire range of alternative rates of return.

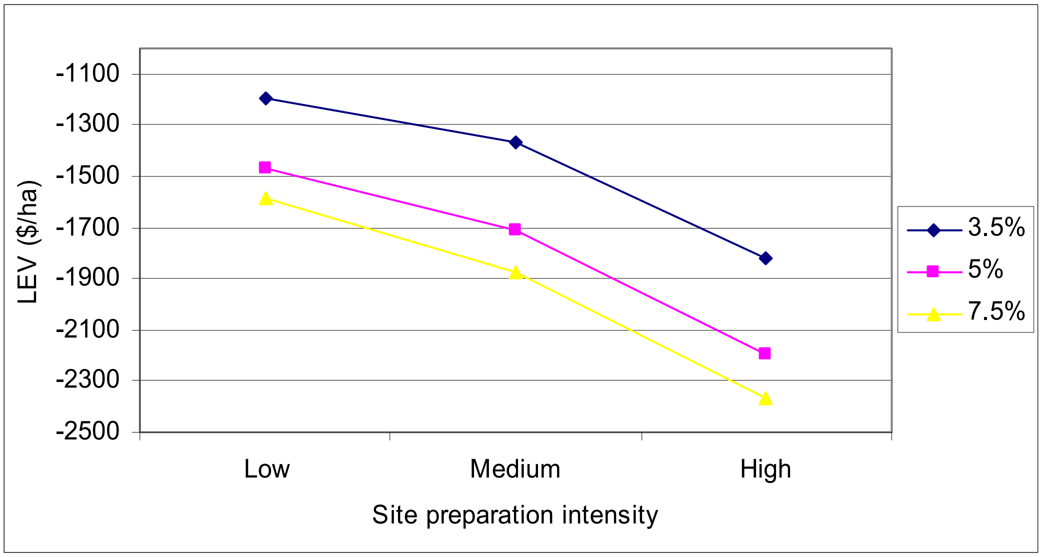

Figure 27 – Effect of alternative rate of return on mixed hardwood LEV (site class III, 60 year rotation, low prices)

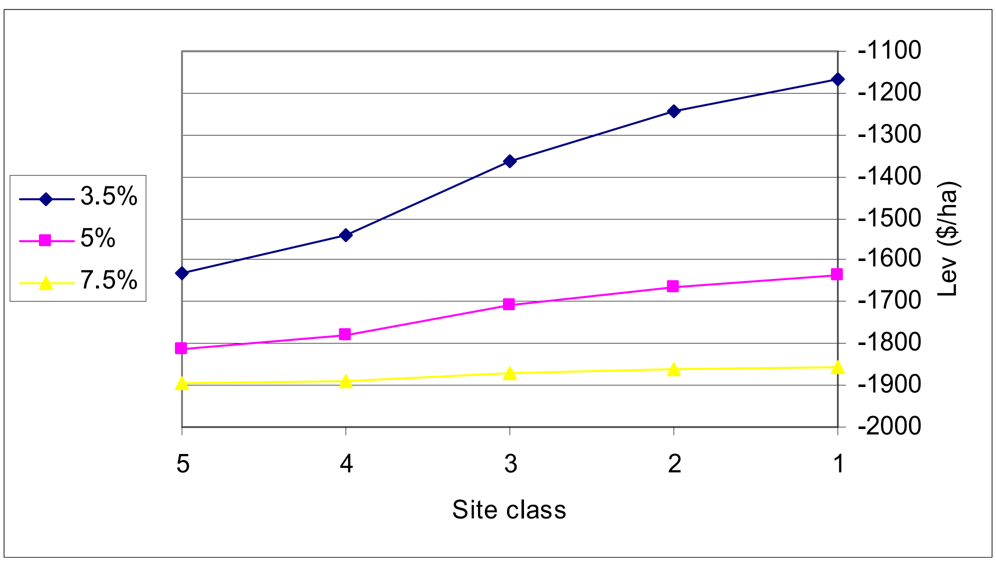

Figure 28 - Effect of alternative rate of return on mixed hardwood LEV (medium intensity site preparation, 60 year rotation, low prices)

Figure 28 shows further that, for a given site class, mixed hardwood LEV tends to decrease with increasing alternative rate of return. It is also evident that increases in mixed hardwood LEV when moving from poorer site classes to better site classes become less pronounced with increasing alternative rates of return. Based on the aforementioned observation, it seems that the quality of a site becomes less significant as part of the decision-making process, as the alternative rate of return increases.

Furthermore, Figure 29 shows that the trend of decreasing mixed hardwood LEV with increasing rotation age, within the proposed rotation age range, is consistent over the 3.5% - 7.5% range of alternative rate of return. Also, for a given rotation age, mixed hardwood LEV appears to decrease with increasing alternative rate of return.

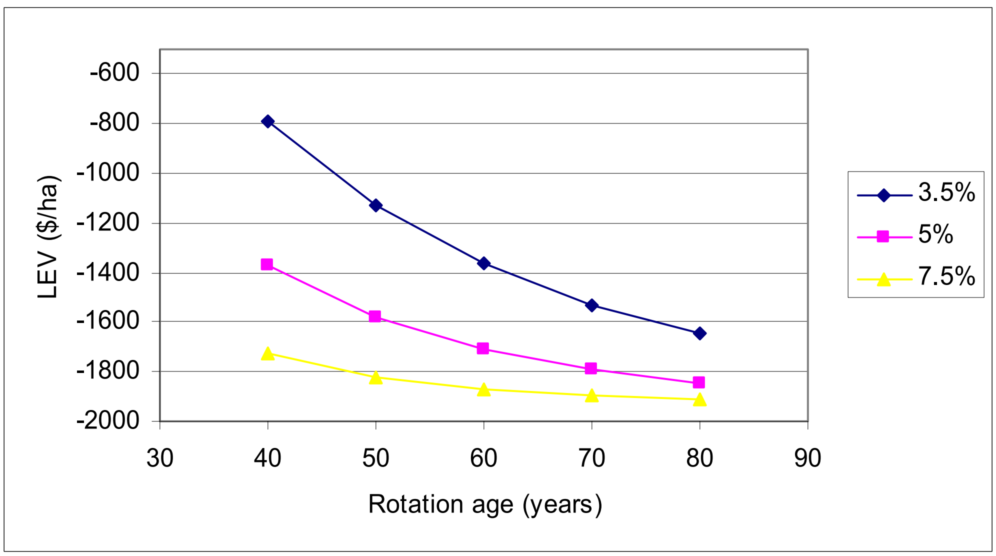

Figure 29 – Effect of alternative rate of return on mixed hardwood LEV over a range of rotation ages (site class III, medium intensity site preparation, low prices)

White pine

Figure 30 shows that, for a given site preparation intensity, white pine LEVs tend to decrease with increasing alternative rate of return. The trends displayed, however, are not consistent over the full range of alternative rates of return. Results suggest that with an ARR of 3.5%, white pine LEV is maximized under high intensity site preparation. With an ARR of 5%, white pine LEV is maximized under medium intensity site preparation. With an ARR of 7.5%, it appears that white pine LEV is maximized under low intensity site preparation. Thus, this trend would suggest that, with the objective of maximizing LEV, the optimal intensity of site preparation decreases as the alternative rate of return increases. This would seem logical, as the higher the opportunity cost of money, the less money one would want to invest in site preparation.

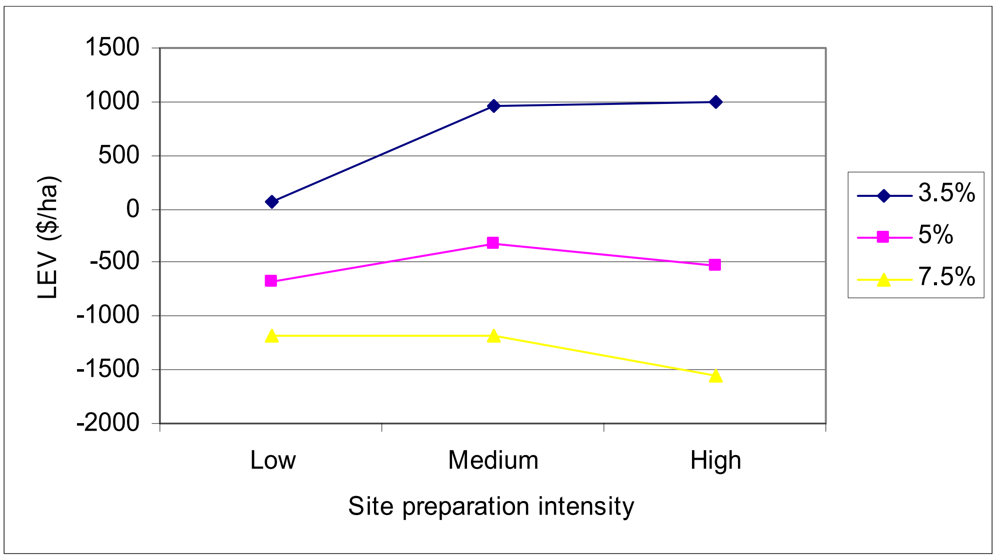

Figure 30 – Effect of alternative rate of return on white pine LEV (site class III, 30 year rotation, low prices)

As for the mixed hardwoods, Figure 31 shows that, for a given site class, white pine LEV tends to decrease with increasing alternative rate of return. It is also evident that increases in white pine LEV when moving from poorer site classes to better site classes become less pronounced with increasing alternative rates of return. Based on the aforementioned observation, it would seem that the quality of a site becomes less significant as part of the decision-making process, as the alternative rate of return increases.

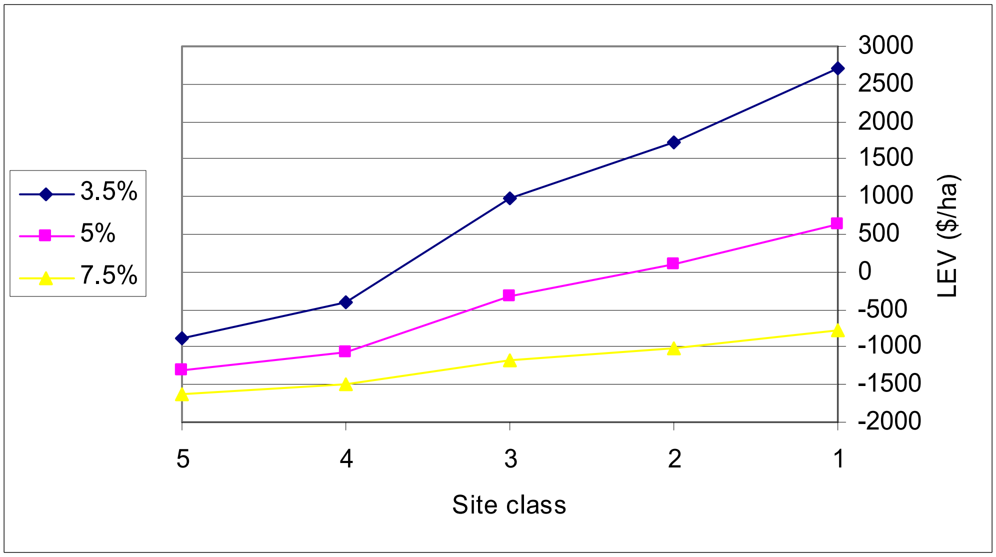

Figure 31 - Effect of alternative rate of return on white pine LEV (medium intensity site preparation, 30 year rotation, low prices)

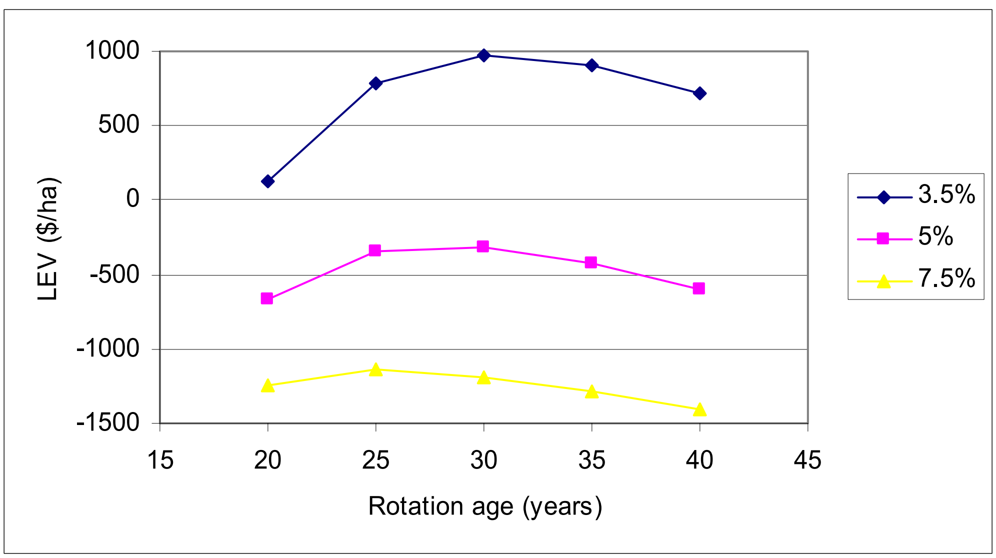

Figure 32 – Effect of alternative rate of return on white pine LEV over a range of rotation ages (site class III, medium intensity site preparation, low prices)

Figure 32 shows further that, in maximizing white pine LEV, the optimal rotation age remains within the range of 25-35 years over the 3.5% - 7.5% range of alternative rate of return. It appears that, with the objective of maximizing LEV, the optimal rotation age decreases with increasing alternative rate of return. This would seem logical, as the higher the opportunity cost of money, the shorter period of time one would want to keep money tied up in the forestry investment. It is also clear that, for a given rotation age, white pine LEV tends to decrease with increasing alternative rate of return.

IV.3.1.E. Ranges of LEVs

As previously discussed, the general trends displayed by the results are of primary importance in this study. Of secondary importance are the actual LEV estimates for the proposed land-use conversion scenarios. These estimates are by no means numbers based on which land-use decisions should be made. However, these estimates do offer landowners a broad range of potential LEVs they may expect under various land-use conversion scenarios. Hence, these LEV ranges will be presented in this section, in terms of a minimum LEV, a base case LEV and a maximum LEV.

Hardwoods

Under the low price set, the highest mixed hardwood LEV yielded within the 3.5%-7.5% ARR range was -$145.58/ha. This maximum LEV represents a mixed hardwood plantation on a site class I site with low intensity site preparation, on a 40 year rotation, with an alternative rate of return of 3.5% (Table 26).

Table 26 – Mixed hardwood LEVs - $/ha - (40 year rotation, 3.5% ARR, low prices)

	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	-1126.51	-1355.14	-1851.30
4	-958.42	-1160.82	-1484.60
3	-764.10	-794.12	-1202.72
2	-423.41	-542.30	-1078.01
1	-145.58	-387.53	-1078.01

The base case scenario for mixed hardwoods, represented by a 60 year rotation, a site class III site with medium intensity site preparation, and an alternative rate of return of 5% (Table 24), yields a LEV of -$1710.16/ha under the low price set. Under the low price set, the lowest mixed hardwood LEV yielded within the 3.5%-7.5% ARR range was -$2416.71/ha. This minimum LEV represents a mixed hardwood plantation on a site class V site with high intensity site preparation, on an 80 year rotation, with an alternative rate of return of 7.5% (Table 27).

Table 27 – Mixed hardwood LEVs - $/ha - (80 year rotation, 7.5% ARR, low prices)

	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	-1621.71	-1917.35	-2416.71
4	-1619.92	-1915.27	-2412.79
3	-1617.84	-1911.35	-2409.77
2	-1614.20	-1908.66	-2408.44
1	-1611.23	-1907.01	-2408.44

White pine

Under the low price set, the highest white pine LEV yielded within the 3.5%-7.5% ARR range was $2697.98/ha. This maximum LEV represents a white pine plantation on a site class I site with medium intensity site preparation, on a 30 year rotation, with an alternative rate of return of 3.5% (Table 28).

Table 28 – White pine LEVs - $/ha - (30 year rotation, 3.5% ARR, low prices)

	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	-768.42	-873.41	-1243.99
4	-379.93	-402.45	167.60
3	58.18	969.32	989.94
2	1368.31	1716.93	1896.26
1	2177.56	2697.98	2462.32

The base case scenario for white pine, represented by a 30 year rotation, a site class III site with medium intensity site preparation, and an alternative rate of return of 5% (Table 25), yields a LEV of -$316.06/ha under the low price set. Under the low price set, the lowest white pine LEV yielded within the 3.5%-7.5% ARR range was -$2330.53/ha. This minimum LEV represents a white pine plantation on a site class V site with high intensity site preparation, on a 20 year rotation, with an alternative rate of return of 5% (Table 29). It is interesting to note that this minimum white pine LEV did not occur under the highest alternative rate of return (7.5%) as one may have expected, but rather, it occurred under a 5% ARR. This result seems to contradict basic economic principles, which would suggest that LEV decreases with an increase in ARR. However, this rather unique case is explainable. When dealing with some negative NPVs, raising the ARR results in future NPVs being discounted such that future NPVs are smaller i.e. raising the ARR makes future losses count less for some negative NPVs. This decrease in future NPVs results in an increase in LEV. This increase in LEV with an increase in ARR is unique to scenarios in which absolute revenues are less than absolute costs.

Table 29 – White pine LEVs - $/ha - (20 year rotation, 5% ARR, low prices)

	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	-1508.30	-1770.91	-2330.53
4	-1275.35	-1488.51	-1484.08
3	-1012.64	-665.94	-990.97
2	-227.03	-217.64	-447.51
1	258.23	370.64	-108.07

IV.3.1.F. Comparison of mixed hardwood and white pine LEVs

Table 30 shows that, over a range of scenarios, white pine LEVs tend to be higher than the mixed hardwood LEVs. It is also evident that not one of the investigated mixed hardwood scenarios yielded a positive LEV, whereas a number of the white pine scenarios did yield positive LEVs within the 3.5% - 5% range of alternative rate of return. However, all investigated white pine scenarios with an alternative rate of return greater than 5% yielded negative LEVs. According to results, under the low price assumption, in terms of LEV, an investment in a 30 year rotation white pine regime, under medium intensity site preparation on a site class III site, is worth $1394.10/ha more than a similar investment in a 60 year rotation mixed hardwood regime.

Table 30 – Comparison of mixed hardwood and white pine LEVs (low prices)

LEV		Mixed hardwoods	White pine
Low	*LEV ($/ha)*	**-2416.71**	**-2330.53**
	Rotation	80 years	20 years
	Site class	V	V
	Site preparation	High	High
	ARR	7.5%	5%
Base case	*LEV ($/ha)*	**-1710.16**	**-316.06**
	Rotation	60 years	30 years
	Site class	III	III
	Site preparation	Medium	Medium
	ARR	5%	5%
High	*LEV ($/ha)*	**-145.58**	**2697.98**
	Rotation	40 years	30 years
	Site class	I	I
	Site preparation	Low	Medium
	ARR	3.5%	3.5%

IV.3.1.G. Summary

Based on the low price LEV trends that have been discussed, a few primary points of significance can be highlighted. Mixed hardwood LEVs are negative for all of the proposed scenarios. Hence, it appears that converting reclaimed mined lands to mixed hardwood plantations is not financially feasible for any of the proposed scenarios. This lack of financially feasible mixed hardwood scenarios highlights the importance of landowners capturing the changing product ratios with rotation age, which would potentially render some mixed hardwood scenarios financially feasible. Results do suggest a trend of decreasing mixed hardwood LEV with increasing intensity of site preparation, and hence, minimal site preparation seems advisable for most mixed hardwood regimes.

The white pine scenarios did yield a number of positive LEVs. These financially feasible white pine scenarios occur primarily on site class I and II sites, within the 3.5% - 5% range of alternative rate of return, for all site preparation intensities. The most profitable of these scenarios occurs on a site class I site, under medium intensity site preparation, with a 3.5% alternative rate of return, and on a 30 year rotation. According to white pine results, LEV is maximized on site classes I, II and III under medium intensity site preparation, and LEV is maximized on site classes IV and V under low intensity site preparation. This trend does depend, however, on the alternative rate of return. Results suggest that, for a given site class, the optimal intensity of site preparation increases with decreasing alternative rate of return for white pine scenarios. For both mixed hardwood and white pine scenarios, the quality of a site appears to become less significant as part of the decision-making process, as the alternative rate of return increases.

IV.3.2. Incentives

As pertains to this study, an incentive is a payment that is offered to a landowner in an effort to render a land-use conversion profitable and a more appealing option to the landowner. Three types of incentives are considered for this study: 1) lump sum payment, paid at the time of planting. 2) revenue incentive, paid at harvest (and corresponding series of annual payments) and 3) payment based on carbon volume. The provider of this incentive will no doubt have financial limitations as to how much money can be spent on these incentive payments. Hence, useful to the incentive provider is a range of potential incentive payment values, over a spectrum of possible land-use conversion scenarios. For the sake of this study, incentive values have been calculated for the low price subset of scenarios that assume a rotation age of 60 years and 30 years for mixed hardwoods and white pine respectively, and that are in the 3.5% - 7.5% range of alternative rate of return. Results will only be presented and discussed for scenarios with an alternative rate of return of 5%, as trends are fairly consistent throughout the 3.5% - 7.5% range. However, full results will be presented in Appendix B. As opposed to the mixed hardwoods, many of the white pine scenarios yielded positive LEVs. However, incentives may only be necessary for scenarios that yield negative LEV values; hence the limited number of white pine scenarios for which incentives have been calculated within the selected subset of scenarios. For the sake of comparison between mixed hardwoods and white pine, incentive values have also been calculated, and will be presented for scenarios corresponding to the high, low and base case LEV scenarios.

IV.3.2.A. Lump sum payment paid at the time of planting, and related set of annual payments

The lump sum payment equates to a one-time payment made at the time of planting, which would render a given scenario economically feasible for a landowner. This lump sum payment is equal to the dollar value that would sum to zero with the corresponding negative LEV value. This incentive would reduce the burden for a landowner, in that he/she would be able to undertake this land-use conversion with some up-front financial backing. So too, this up-front payment could go towards covering the site preparation and forest establishment costs. The money could also be invested elsewhere. However, a landowner may prefer to spread payments out throughout the duration of a full rotation; hence the calculation of the annual payments. In reality, the LEV of a given scenario cannot be accurately calculated at the beginning of a rotation, as harvest volumes, revenues and costs can only be accurately calculated at harvest. Hence, the results presented are merely a prediction of incentive ranges one may expect.

Hardwoods

Lump sum payments and corresponding annual payments for mixed hardwoods under the low price set are presented in Tables 31 and 32, respectively, for all scenarios that assume a rotation age of 60 years and an alternative rate of return of 5%.

Table 31 – Mixed hardwood lump sum payment, paid at time of planting, required to yield a non-negative LEV - $/ha – (60 year rotation, 5% ARR, low prices)

	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	1532.35	1814.41	2316.93
4	1501.11	1778.30	2248.79
3	1465.01	1710.16	2196.42
2	1401.70	1663.37	2173.24
1	1350.08	1634.61	2173.24

Table 32 – Mixed hardwood equal annual payment required to yield a non-negative LEV - $/ha/yr – (60 year rotation, 5% ARR, low prices)

	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	76.62	90.72	115.85
4	75.06	88.91	112.44
3	73.25	85.51	109.82
2	70.09	83.17	108.66
1	67.50	81.73	108.66

These incentive values display trends exactly opposite to those trends displayed by the LEVs of the corresponding mixed hardwood scenarios. In short, as mixed hardwood LEVs increase, incentive values decrease. Mixed hardwood incentive values tend to decrease when moving from poor quality sites (site class V) to good quality sites (site class I), and tend to increase with increasing site preparation intensity and with increasing alternative rate of return. Thus, results suggest that the poorer the site quality, the higher the site preparation intensity, and the higher the alternative rate of return, the higher the incentive necessary to render a land-use conversion to mixed hardwoods profitable for a landowner.

White pine

Lump sum payments and corresponding annual payments for white pine under the low price set are presented in Tables 33 and 34, respectively, for all scenarios that assume a rotation age of 30 years and an alternative rate of return of 5%.

Table 33 – White pine lump sum payment, paid at time of planting, required to yield a non-negative LEV - $/ha – (30 year rotation, 5% ARR, low prices)

	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	1125.97	1318.31	1747.07
4	914.67	1062.16	979.31
3	676.38	316.06	532.05
2	*	*	39.10
1	*	*	*

* indicates LEV is positive without additional payments

Table 34 – White pine equal annual payment required to yield a non-negative LEV - $/ha/yr – (30 year rotation, 5% ARR, low prices)

	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	56.30	65.92	87.35
4	45.73	53.11	48.97
3	33.82	15.80	26.60
2	*	*	1.96
1	*	*	*

* indicates LEV is positive without additional payments

These incentive values display trends exactly opposite to those trends displayed by the LEVs of the corresponding white pine scenarios. As is the case with the mixed hardwoods, as white pine LEVs increase, corresponding incentive values decrease. White pine incentives tend to decrease when moving from poor quality sites (site class V) to good quality sites (site class I), and tend to increase with increasing alternative rate of return. Other than these two common trends, as for the LEVs, these white pine incentives exhibit some different trends to those of the mixed hardwoods. Results suggest that when moving from poorer quality sites (site class V) to better quality sites (site class III), maximum incentive payments tend to occur with decreasing site preparation intensity.

IV.3.2.B. Payment based on revenue received at harvest

The payment based on the revenue received at harvest is a one-time payment made at the time of harvest. This payment equates to the per hectare dollar amount by which the revenue received from sawtimber and pulpwood sales at harvest would have to increase in order to render a given scenario economically feasible for the landowner. One advantage of such an incentive is the fact that it can be accurately determined at the end of a rotation, as it is not based on predicted costs and revenues, but rather on actual costs incurred and actual revenues received during the rotation and at harvest. A disadvantage of such an incentive would be the risk that the landowner undertakes, in that he/she will only be "rewarded" for what remains standing at the end of a rotation. There would be no guarantee against natural disasters, which could damage or destroy the landowner's crop and render the harvest at rotation age fruitless.

Hardwoods

Payments based on increase in revenue at harvest for mixed hardwoods under the low price set are presented in Table 35 for all scenarios that assume a rotation age of 60 years and an alternative rate of return of 5%. These mixed hardwood incentive values are rather large, especially given the fact that they are per hectare payments. These large values are a result of the time value of money being taken into account over a long period of time i.e., a 60 year rotation. The trends displayed by these mixed hardwood incentives based on revenue received at harvest are consistent with those displayed by the other incentives considered in this study.

Table 35 - Mixed hardwoods revenue incentive required at harvest to yield non-negative LEVs - $/ha - (60 year rotation, 5% ARR, low prices)

	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	27090.65	32077.21	40961.42
4	26538.47	31438.86	39756.83
3	25900.11	30234.27	38830.85
2	24780.95	29407.04	38421.18
1	23868.29	28898.61	38421.18

White pine

Payments based on increase in revenue at harvest for white pine under the low price set are presented in Table 36 for all scenarios that assume a rotation age of 30 years and an alternative rate of return of 5%. The trends displayed by these white pine incentives based on revenue received at harvest are consistent with those displayed by the other incentives considered in this study.

Table 36 - White pine revenue incentive required at harvest to yield non-negative LEVs - *$/ha - (30 year rotation, 5% ARR, low prices)*

	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	3740.39	4379.36	5803.68
4	3038.47	3528.43	3253.23
3	2246.89	1049.92	1767.43
2	*	*	129.90
1	*	*	*

* indicates LEV is positive without additional payments

IV.3.2.C. Payment based on carbon volume

The payment based on carbon volume is an annual payment made to the landowner throughout the duration of a rotation. This incentive equates to the dollar amount per ton of carbon present in a given forest stand that would have to be offered to a landowner on an annual basis in order to render the given land use conversion economically feasible for the landowner. The purpose of this incentive is to encourage the landowner to delay harvesting as long as possible. This objective is achieved by not only “rewarding” the landowner for the carbon volume growth increment from year to year, but rather the cumulative carbon volume present at the end of each year. In other words, to delay harvest by one more year would mean being “rewarded” for the carbon volume that was present at the end of the previous year plus the carbon volume growth increment during the last year of growth. Due to this incentive being paid on an annual basis, the level of risk assumed by the landowner is reduced, in that he/she does not have to wait until the end of a rotation for an incentive payment, but can rather make decisions on a year-to-year basis. This incentive is also a source of steady income for the landowner throughout a rotation. At the same time, given the uncertainty of carbon markets in the future, a carbon subsidy scheme could be a rather risky incentive scheme upon which to base a land-use conversion decision.

Hardwoods

Payments based on carbon volume for mixed hardwoods under the low price set are presented in Table 37 for all scenarios that assume a rotation age of 60 years and an alternative rate of return of 5%. The trends displayed by these mixed hardwood incentives based on carbon volume are once again consistent with those displayed by the other incentives considered in this study.

Table 37 – Mixed hardwood carbon subsidy required to yield non-negative LEVs - $/ton of carbon, paid annually – (60 year rotation, 5% ARR, low prices)

	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	2.45	2.54	2.82
4	2.10	2.17	2.39
3	1.79	1.82	2.03
2	1.51	1.56	1.90
1	1.27	1.43	1.90

This incentive based on carbon volume could be paid in terms of an annual per hectare payment. This per hectare payment would be dynamic in that it would increase from year to year at the rate at which carbon is sequestered. For example, 10^{th} year, 30^{th} year and 60^{th} year per hectare payments (not discounted) made on a mixed hardwood plantation (60 year rotation), on a site class III site, with low intensity site preparation, under low prices and a 5% ARR, would be $60.52/ha, $122.63/ha and $146.52/ha respectively. Total per hectare payments made over the full 60 year rotation would sum to approximately $6404.65/ha (not discounted).

White pine

Payments based on carbon volume for white pine under the low price set are presented in Table 38 for all scenarios that assume a rotation age of 30 years and an alternative rate of return of 5%.

Table 38 – White pine carbon subsidy required to yield non-negative LEVs - $/ton of carbon, paid annually – (30 year rotation, 5% ARR, low prices)

	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	4.13	3.99	4.36
4	2.72	2.61	1.98
3	1.66	0.64	0.89
2	*	*	0.05
1	*	*	*

* indicates LEV is positive without additional payments

The trends displayed by these white pine incentives based on carbon volume differ slightly from the trends displayed by the other white pine incentives considered in this study, particularly on the poorer quality sites (site classes IV and V). This could be due to the fact that the carbon payment is the only incentive (in this study) based on cumulative volumes i.e., payments are made on an annual basis, "rewarding" the landowner, not only for the carbon volume increment for a given year, but also for the volume of carbon present at the end of the previous year. For corresponding scenarios, the other incentives display a clear trend of increasing white pine subsidy with increasing site preparation intensity on a site class V site. Results for this incentive based on carbon volume, however, suggest that the minimum subsidy on a site class V site would coincide with medium site preparation intensity. So too, for corresponding scenarios, trends displayed by the other incentives suggest that the maximum subsidy payment on a site class IV site coincides with medium site preparation intensity, followed by high intensity site preparation, with the lowest subsidies coinciding with a low intensity site preparation. Results for this incentive based on carbon volume, however, suggest a clear trend of decreasing subsidy payment with increasing intensity of site preparation on a site class IV site.

As for the mixed hardwoods, this incentive based on carbon volume could be paid in terms of an annual per hectare payment. For example, 5th year, 15th year and 30th year per hectare payments (not discounted) made on a white pine plantation (30 year rotation), on a site class III site, with low intensity site preparation, under low prices and a 5% ARR, would be $0.45/ha, $42.15/ha and $131.48/ha respectively. Total per hectare payments made over the full 30 year rotation would sum to approximately $1560.97/ha (not discounted).

IV.3.2.D. Comparison of mixed hardwood and white pine incentive values

It is evident from the results that the mixed hardwood incentive ranges are higher than those of the white pine incentives for all three incentive types investigated in this study. This is to be expected, as the range of mixed hardwood LEVs was lower than that of the white pine. These ranges of incentives for both mixed hardwoods and white pine are compared in Tables 39 - 42. The “high” incentive values correspond with the “low” LEVs, the “base case” incentive values correspond with the “base case” LEVs, and the “low” incentive values correspond with the “high” LEVs previously presented in Table 32. In the case of white pine, a number of scenarios yielded positive LEVs. For such scenarios, incentives to convert land would not be necessary, in that the given scenario is already an economically feasible option. Hence, the lowest incentive value, represented by all scenarios that yielded positive LEVs, is $0. Therefore, the value of $0 has been assigned to all the "low" white pine incentive values in the following tables of comparison.

Table 39 – Comparison of mixed hardwood and white pine lump sum payments (low *prices)*

Lump sum		**Mixed hardwoods**	**White pine**
High	*Lump sum ($/ha)*	**2416.71**	**2330.53**
	Rotation	80 years	20 years
	Site class	V	V
	Site preparation	High	High
	ARR	7.5%	5%
Base case	*Lump sum ($/ha)*	**1710.16**	**316.06**
	Rotation	60 years	30 years
	Site class	III	III
	Site preparation	Medium	Medium
	ARR	5%	5%
Low	*Lump sum ($/ha)*	**145.58**	**0**
	Rotation	40 years	*
	Site class	I	*
	Site preparation	Low	*
	ARR	3.5%	*

Mixed hardwoods lump sum payments, made at the time of planting, range from a minimum of $145.58/ha to a maximum of $2416.71/ha (Table 39). The corresponding range for mixed hardwood annual payments is $5.10/ha to $181.25/ha (Table 40). White pine lump sum payments, made at the time of planting, range from a minimum of $0/ha to a maximum of $2330.53/ha (Table 39). The corresponding range for white pine annual payments is $0/ha to $116.53/ha (Table 40). Thus, for example, under scenarios that yield the maximum LEV for mixed hardwoods and white pine, respectively, the incentive provider, in order to render a conversion to mixed hardwoods economically feasible, would have to offer the landowner a lump sum payment at planting that is $145.58/ha greater (or an annual payment that is $5.10/ha greater) than would be the case for a conversion to white pine. So too, according to results, under scenarios that yield the minimum LEV for mixed hardwoods and white pine, respectively, the incentive provider, in order to render a conversion to mixed hardwoods economically feasible, would have to offer the landowner a lump sum payment at planting that is $86.18/ha greater (or an annual payment that is $64.72/ha greater) than would be the case for a conversion to white pine.

Table 40 – Comparison of mixed hardwood and white pine annual payments (low prices)

Annual payment		Mixed hardwoods	White pine
High	*Annual payments ($/ha/year)*	**181.25**	**116.53**
	Rotation	80 years	20 years
	Site class	V	V
	Site preparation	High	High
	ARR	7.5%	5%
Base case	*Annual payments ($/ha/year)*	**85.51**	**15.80**
	Rotation	60 years	30 years
	Site class	III	III
	Site preparation	Medium	Medium
	ARR	5%	5%
Low	*Annual payments ($/ha/year)*	**5.10**	**0**
	Rotation	40 years	*
	Site class	I	*
	Site preparation	Low	*
	ARR	3.5%	*

Mixed hardwoods payments based on an increase in revenue at harvest, range from a minimum of $430.82/ha to a maximum of $784449.52/ha (Table 41). White pine payments based on an increase in revenue at harvest, range from a minimum of $0/ha to a maximum of $3853.06/ha (Table 41). Thus, for example, under scenarios that yield the maximum LEV for mixed hardwoods and white pine respectively, the incentive provider, in order to render a conversion to mixed hardwoods economically feasible, would have to offer the landowner a payment at harvest that is $430.82/ha greater than would be the case for a conversion to white pine. So too, according to results, under scenarios that yield the minimum LEV for mixed hardwoods and white pine respectively, the incentive provider, in order to render a conversion to mixed hardwoods economically feasible, would have to offer the landowner a payment at harvest that is $780596.46/ha greater than would be the case for a conversion to white pine.

Table 41 - Comparison of mixed hardwood and white pine increase in revenue at harvest (low prices)

Revenue incentive		Mixed hardwoods	White pine
High	*Increase in revenue ($/ha)*	**784449.52**	**3853.06**
	Rotation	80 years	20 years
	Site class	V	V
	Site preparation	High	High
	ARR	7.5%	5%
Base case	*Increase in revenue ($/ha)*	**30234.27**	**1049.92**
	Rotation	60 years	30 years
	Site class	III	III
	Site preparation	Medium	Medium
	ARR	5%	5%
Low	*Increase in revenue ($/ha)*	**430.82**	**0**
	Rotation	40 years	*
	Site class	I	*
	Site preparation	Low	*
	ARR	3.5%	*

Mixed hardwood payments based on carbon volume, range from a minimum of $0.10/ton of carbon to a maximum of $5.26/ton of carbon (Table 42). White pine payments based on carbon volume, range from a minimum of $0/ton of carbon to a maximum of $11.39/ton of carbon (Table 42). Thus, for example, under scenarios that yield the maximum LEV for mixed hardwoods and white pine respectively, the incentive provider, in order to render a conversion to mixed hardwoods economically feasible, would have to offer the landowner a carbon subsidy that is $0.10/ton of carbon greater than would be the case for a conversion to white pine. So too, according to results, under scenarios that yield the minimum LEV for mixed hardwoods and white pine respectively, the incentive provider, in order to render a conversion to mixed hardwoods economically feasible, would have to offer the landowner a carbon subsidy that is \$6.13/ton of carbon less than would be the case for a conversion to white pine.

Table 42 - Comparison of mixed hardwood and white pine carbon payments (low prices)

Carbon payment		**Mixed hardwoods**	**White pine**
High	*Carbon payment (\$/ton of carbon)*	**5.26**	**11.39**
	Rotation	80 years	20 years
	Site class	V	V
	Site preparation	High	High
	ARR	7.5%	5%
Base case	*Carbon payment (\$/ton of carbon)*	**1.82**	**0.64**
	Rotation	60 years	30 years
	Site class	III	III
	Site preparation	Medium	Medium
	ARR	5%	5%
Low	*Carbon payment (\$/ton of carbon)*	**0.10**	**0**
	Rotation	40 years	*
	Site class	I	*
	Site preparation	Low	*
	ARR	3.5%	*

The literature review revealed no other studies that directly calculated carbon subsidies, against which our results could be compared. However, a number of studies did present average per ton costs of sequestering carbon. These per ton costs ranged throughout the literature from \$0/ton of carbon to \$120/ton of carbon. The carbon payments calculated in this study could be interpreted as a cost incurred by the incentive provider in an effort to sequester carbon, and thus, although the numbers are not directly comparable, these incentive values can be interpreted in a similar way to the "costs of carbon sequestration", as reported in a number of studies. Our results yield incentive values that are well within the cost of $20/ton of carbon sequestered, suggested by van Kooten et al. (2000) to be a reasonable cutoff for socially desirable investment in forestry.

IV.3.2.E. Summary

The incentive values calculated for both mixed hardwood and white pine scenarios display trends that are exactly opposite to those displayed by the LEVs of the corresponding scenarios. For both mixed hardwood and white pine scenarios, incentive values increase as site quality decreases. Thus, it would seem more appealing to the incentive provider to offer incentives to landowners, who are willing to undertake a land-use conversion on their best quality sites. Due to the higher average LEVs of white pine scenarios opposed to mixed hardwood scenarios, average white pine incentive values are lower than average mixed hardwood incentive values. This is especially so for the incentive based on an increase in revenue at harvest, where the difference between the white pine and mixed hardwood incentive values is a matter of hundreds of thousands of dollars per hectare for some scenarios. The only case where the white pine incentive value is greater than that of the mixed hardwoods is for the maximum carbon payment scenario. This variation can be attributed to the significantly shorter white pine rotation (as opposed to mixed hardwoods), during which carbon payments can be made to render the land-use conversion economically feasible. The white pine carbon payment may be less than that of the mixed hardwoods, in terms of a per ton payment. However, the sum of all annual per hectare carbon payments (not discounted) made by the end of a 60 year mixed hardwood rotation is approximately four times greater than the sum of all annual per hectare carbon payments (not discounted) made by the end of a 30 year white pine rotation. Hence, the lower per ton mixed hardwood carbon payment is not necessarily the more appealing option.

It appears that, for white pine scenarios, there is not much difference between incentive values for lump sum payments at planting, revenue incentives at harvest, and total carbon payments over a rotation. For mixed hardwoods, however, it appears that the carbon payment incentive is the cheapest option of encouraging landowners to convert land.

IV.4. High price scenarios

The second set of prices used (high prices) in our analysis comprises a set of ideal, high-end prices, where only high-value timber species and top quality timber products are considered. Standing timber prices from the 2003 Pennsylvania Woodlands timber market report were averaged for the following hardwood species: red oak, white oak, black cherry, white ash, yellow poplar and sugar maple (hard maple). The white pine timber price used in the second set of prices is that quoted by Truman Lumber Company (July 2003). Both the hardwood and white pine pulpwood prices are those taken from the 2003 Pennsylvania Woodlands timber market report. All results presented and discussed in the following sections are based on this high set of product prices.

IV.4.1. Land expectation values and incentive values

As for the low price set, in the following sections, the economic feasibility of converting reclaimed mined lands to mixed hardwood and white pine forests will be discussed in terms of LEVs. More specifically, the effects of the following factors on LEV will be analyzed: rotation age, site class, site preparation intensity and alternative rate of return. As for the low price set, three different types of incentives will also be discussed in terms of the high price set.

IV.4.1.A. Effect of rotation age and site class on LEV

Similar to the low price scenarios, the effects of rotation age and site class on the decision to convert reclaimed mined lands to forests are analyzed in the following section for scenarios based on the set of high prices.

Hardwoods

Similar to the low price scenarios, Figure 33 shows a trend of decreasing mixed hardwood LEVs with increasing rotation age for all site classes, using high prices. It is also clear that LEV increases when moving from poorer quality sites (site class V) to good quality sites (site class I). The absence of an obvious maximum LEV or optimal rotation age is again evident. This limitation is once again attributed to the failure to take into account varying product ratios with rotation. In fact, higher prices would result in shorter optimal rotations without taking into account product differentiation.

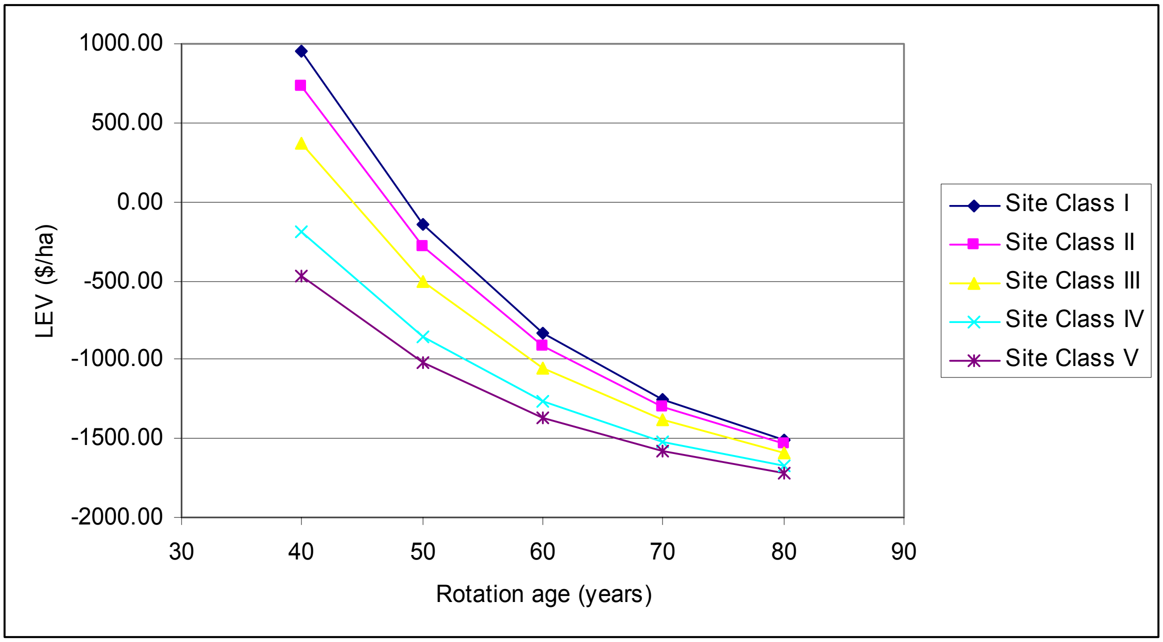

Figure 33 – Mixed hardwood LEV by rotation and site class (medium intensity site preparation, high prices, 5% ARR)

White pine

Figure 34 shows white pine LEV trends over a range of rotation ages, for all site classes. Trends displayed by site classes I – IV are similar to those of the low price scenarios. However, as expected, the high price scenario tends to yield a slightly shorter optimal rotation than the low price scenario on site class V. These high price scenarios suggest an optimal rotation age range of 25 – 30 years, depending on site quality, whereas the low price scenarios yielded an optimal rotation age range of 25 – 35 years. High price LEVs for all white pine scenarios increase significantly from the low price scenarios. For example, on a site class I site, under medium intensity site preparation, with an alternative rate of return of 5% and a 30 year rotation, white pine LEV increases by approximately 91.4%.

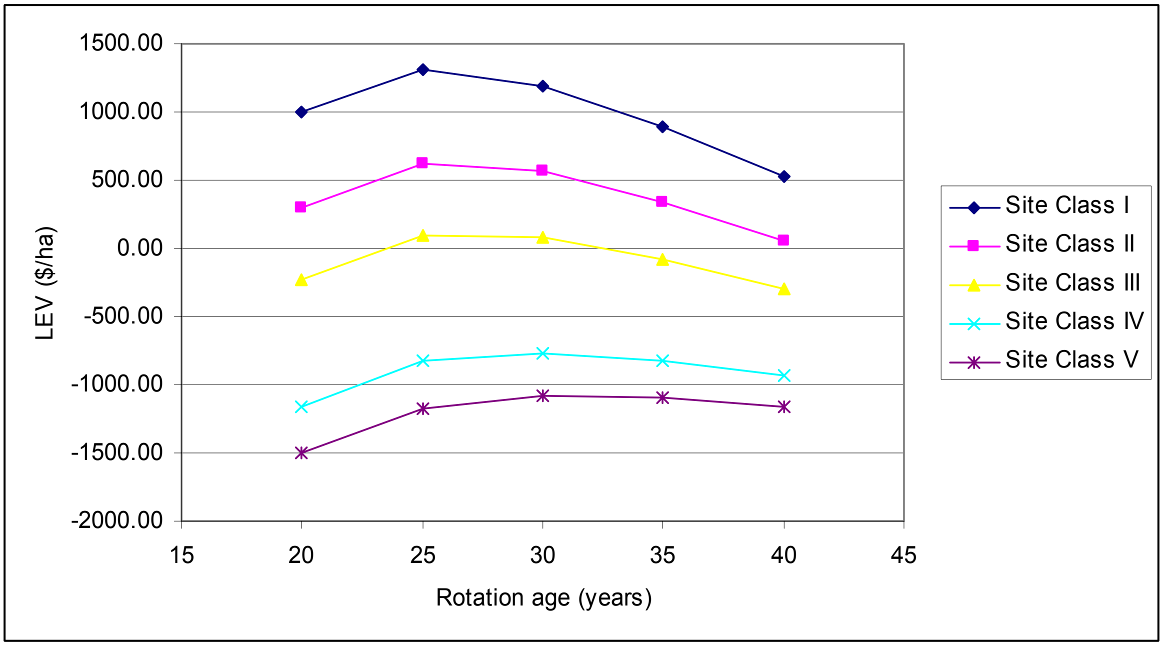

Figure 34 – White pine *LEV by rotation and site class (medium intensity site preparation, high prices, 5% ARR)*

IV.4.1.B. Effect of site preparation intensity and alternative rate of return on LEV

Similar to the low price scenarios, the effects of site preparation intensity and alternative rate of return on the decision to convert reclaimed mined lands to forests are analyzed in the following section for scenarios based on the set of high prices.

Hardwoods

Consistent with the low price scenarios, Figure 35 shows a trend of decreasing mixed hardwood LEV with increasing site preparation intensity on all site classes. Figure 36 shows further that, for this subset of scenarios, the trend of decreasing mixed hardwood LEV with increasing site preparation intensity is constant for the rotation age range of 50 to 80 years. However, for a rotation age shorter than 50 years (and in the range of 40 – 80 years), it appears that mixed hardwood LEV is maximized under medium intensity site preparation.

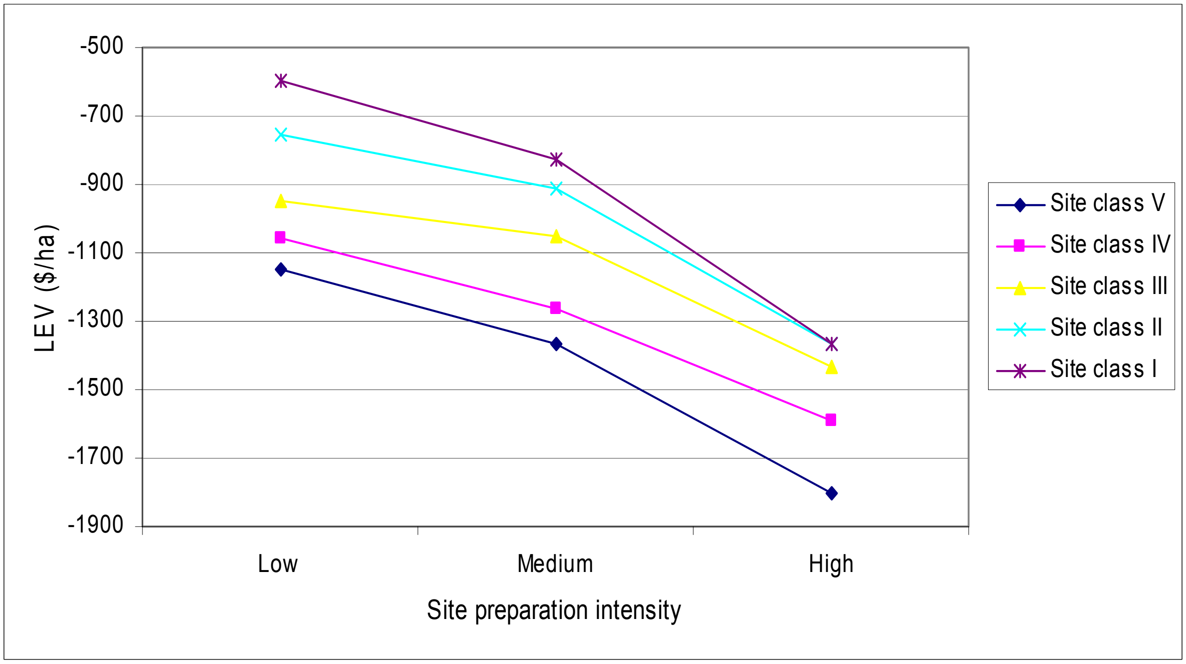

Figure 35 – Effect of site preparation intensity on mixed hardwood LEV by site class (60 year rotation, 5% ARR, high prices)

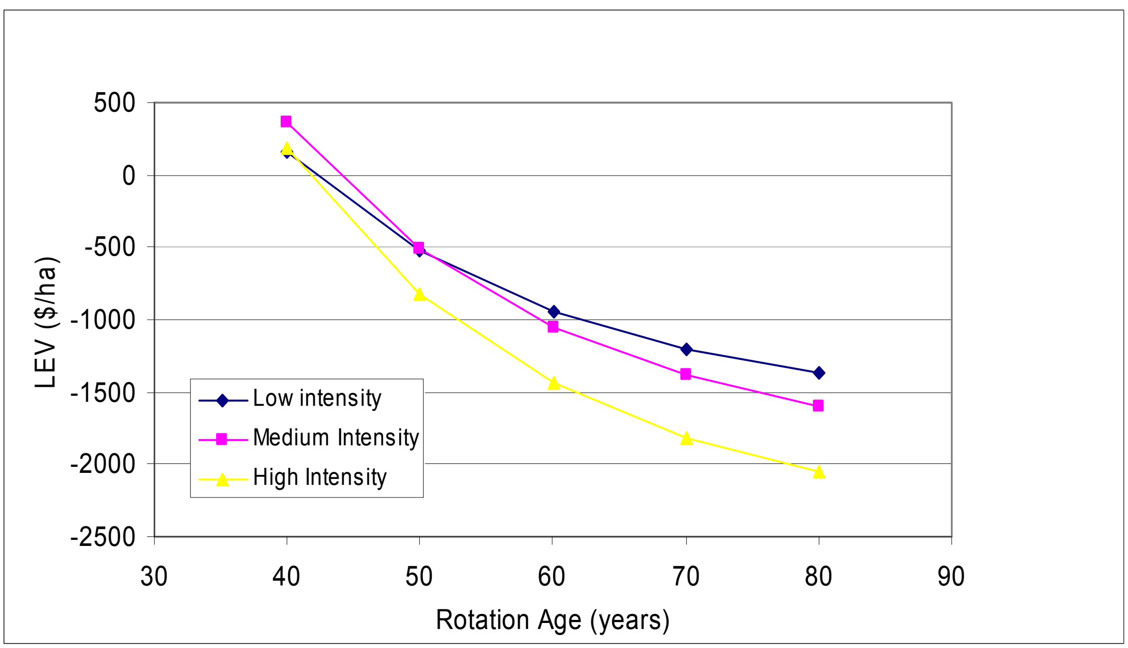

Figure 36 – Effect of site preparation intensity on mixed hardwood LEV, over a range of rotation ages (site class III, 5% ARR, high prices)

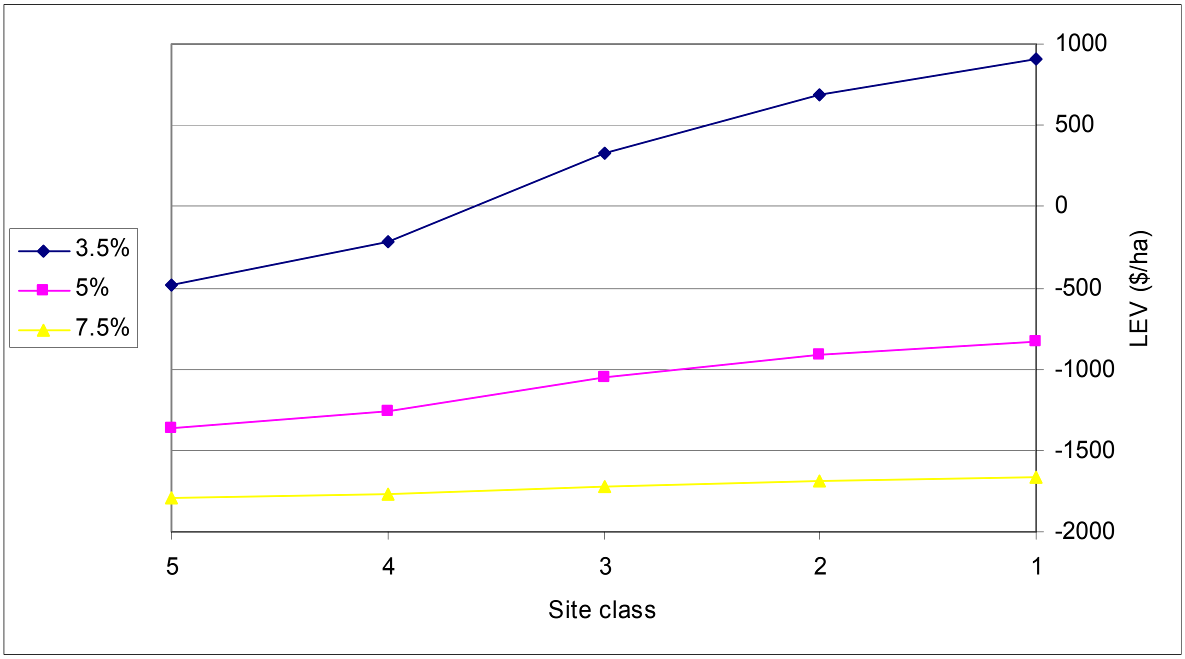

Figure 37 – Effect of alternative rate of return on mixed hardwood LEV by site class (medium intensity site preparation, 60 year rotation, high prices)

Also consistent with the low price scenarios, Figure 37 shows that, for a given site class, mixed hardwood LEV tends to decrease with increasing rate of return. It is also once again evident that increases in mixed hardwood LEV, when moving from poorer quality sites to better quality sites, become less pronounced with increasing alternative rates of return. Figure 38 shows further that the trend of decreasing mixed hardwood LEV with increasing rotation age, within the proposed rotation age range, is consistent over the 3.5% - 7.5% range of alternative rate of return. Also, consistent with the low price scenarios, mixed hardwood LEV appears to decrease with increasing alternative rate of return, for a given rotation age.

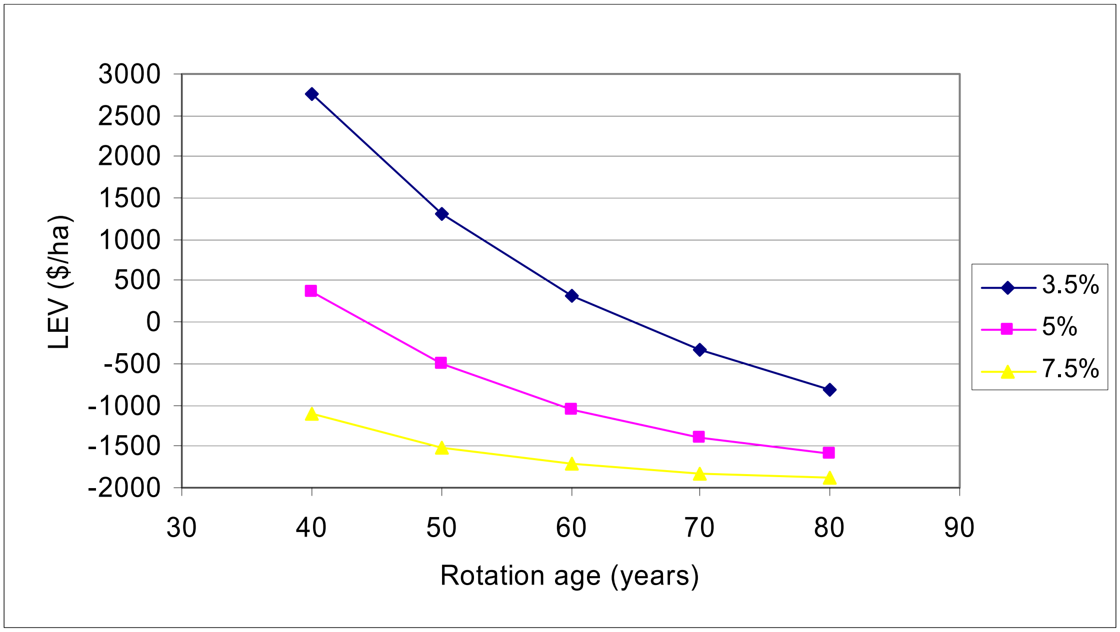

Figure 38 – Effect of alternative rate of return on mixed hardwood LEV over a range of rotation ages (site class III, medium intensity site preparation, high prices)

White pine

Similar to the trends displayed by the low price scenarios, Figure 39 shows that, for the high price scenarios, white pine LEV is maximized on site classes I, II and III under medium intensity site preparation, and LEV is maximized on site class V under low intensity site preparation. The only obvious difference from the low price scenarios is that LEV appears to be maximized on site class IV under high intensity site preparation (high prices), as opposed to the low price scenario, in which LEV is maximized on site class IV under low intensity site preparation. This apparent increase in LEV when moving from medium to high intensity site preparation can, in part, be attributed to the substantial increase in sawtimber to pulpwood ratio when moving from a site class V site to a site class IV site.

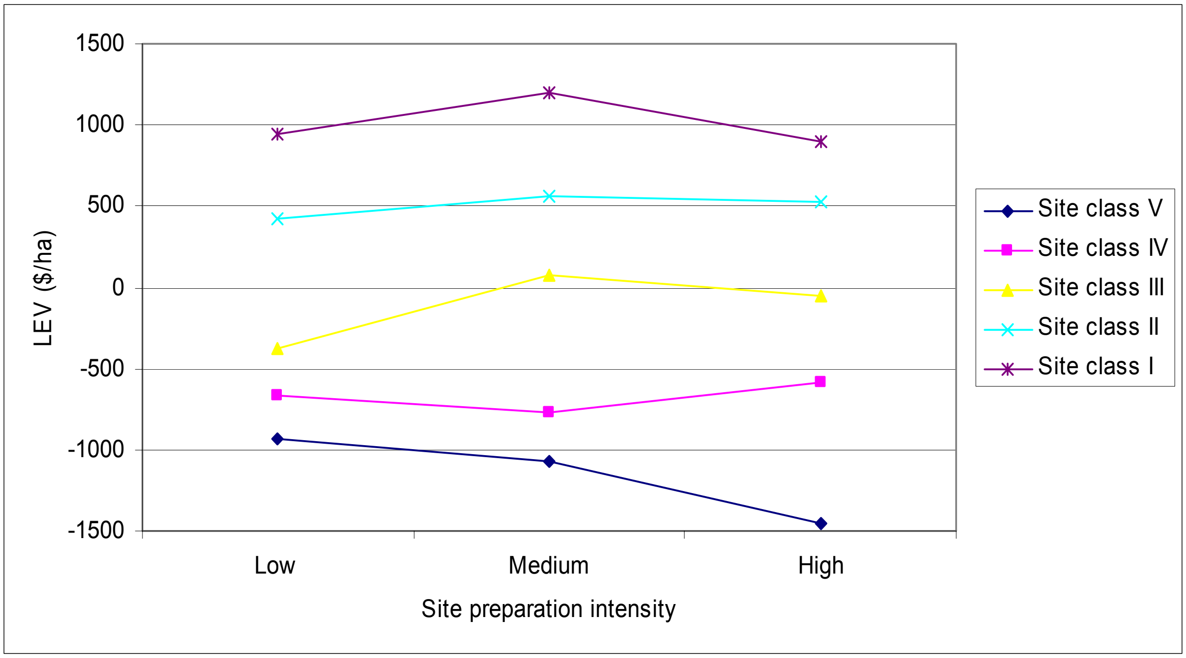

Figure 39 – Effect of site preparation intensity on white pine LEV by site class (30 year rotation, 5% ARR, high prices)

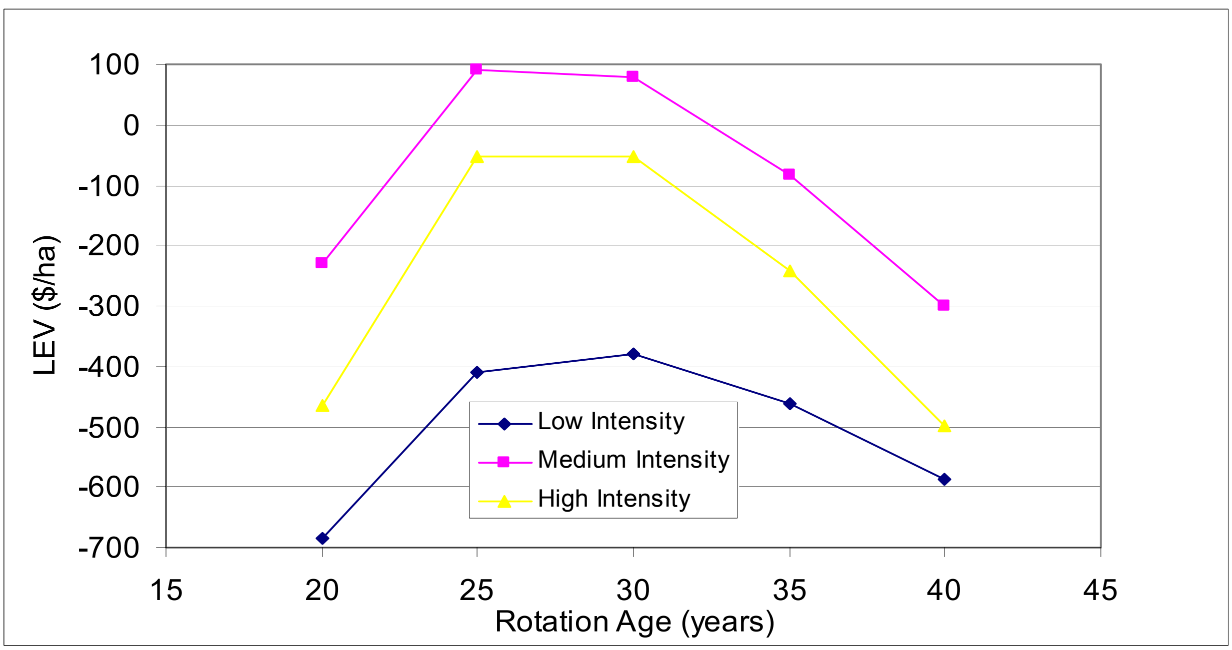

Figure 40 – Effect of site preparation intensity on white pine LEV, over a range of rotation ages (site class III, 5% ARR, high prices)

Thus, results suggest that, for the presented subset of scenarios, the increased cost of increasing site preparation intensity from medium to high intensity is outweighed, on a site class IV site, by the increase in revenue brought about by an increase in sawtimber to pulpwood ratio, and the increase in timber and pulpwood volume produced at harvest. Results presented in Figure 40 suggest that, for the given subset of scenarios, on a site class III site, and for a 5% alternative rate of return, white pine LEV is maximized, for all proposed rotation ages, under a medium intensity site preparation regime.

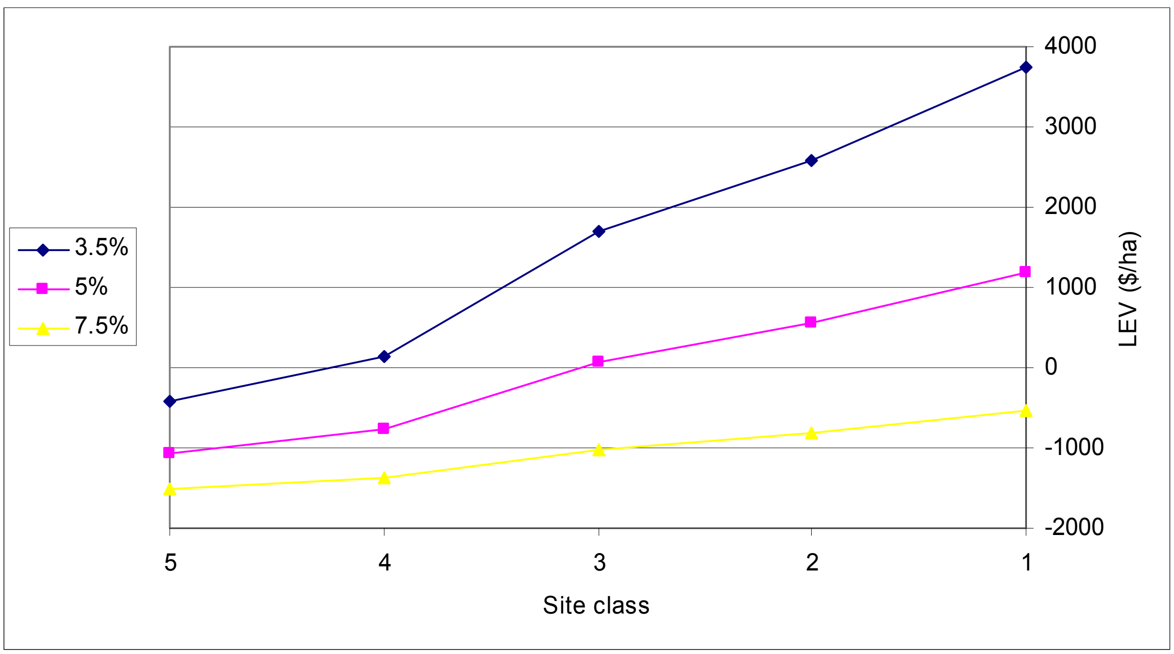

Figure 41 – Effect of alternative rate of return on white pine LEV by site class (medium intensity site preparation, 30 year rotation, high prices)

Consistent with the low price scenarios, Figure 41 shows that, for a given site class, white pine LEV decreases with increasing alternative rate of return. It is also once again evident that increases in white pine LEV, when moving from poorer quality sites to better quality sites, become less pronounced with increasing alternative rates of return. Figure 42 shows that, in maximizing white pine LEV, the optimal rotation age remains within the range of 25 – 30 years over the 3.5% - 7.5% range of alternative rate of return. As for the low price scenarios, it also appears that the optimal rotation age decreases with increasing alternative rate of return. It is also clear that, for a given rotation age, white pine LEV decreases with increasing alternative rate of return.

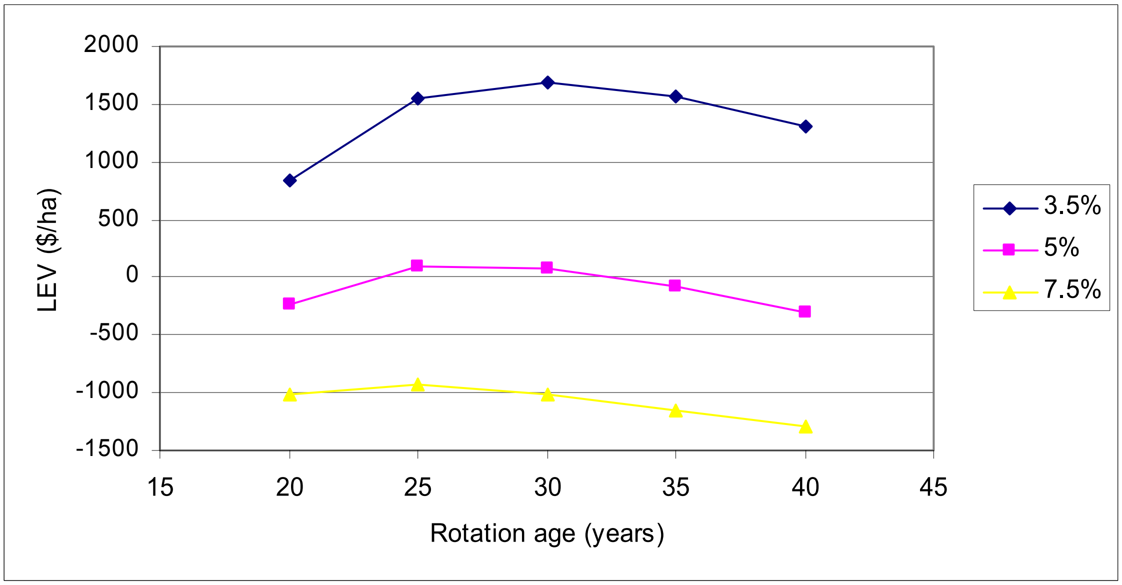

Figure 42 – Effect of alternative rate of return on white pine LEV over a range of rotation ages (site class III, medium intensity site preparation, high prices)

IV.4.1.C. Comparison of mixed hardwood and white pine LEV ranges

Results for the high price scenarios suggest that, within the 3.5% - 7.5% range of alternative rate of return, results for the mixed hardwood scenarios exhibit a wider range of LEVs than those for the white pine. Under the high price set, the highest mixed hardwood LEV yielded within the 3.5% - 7.5% ARR range was $3955.72/ha. This maximum LEV represents a mixed hardwood plantation on a site class I site with low intensity site preparation, on a 40 year rotation, with an alternative rate of return of 3.5% (Table 43).

Table 43 – Comparison of mixed hardwood and white pine LEV ranges (high prices)

LEV		Mixed hardwoods	White pine
Low	*LEV ($/ha)*	**-2387.05**	**-2158.81**
	Rotation	80 years	20 years
	Site class	V	V
	Site preparation	High	High
	ARR	7.5%	7.5%
Base case	*LEV ($/ha)*	**-1051.43**	**78.32**
	Rotation	60 years	30 years
	Site class	III	III
	Site preparation	Medium	Medium
	ARR	5%	5%
High	*LEV ($/ha)*	**3955.72**	**3746.65**
	Rotation	40 years	30 years
	Site class	I	I
	Site preparation	Medium	Medium
	ARR	3.5%	3.5%

The base case scenario for mixed hardwoods, represented by a 60 year rotation, a site class III site with medium intensity site preparation, and an alternative rate of return of 5% (Table 43), yields a LEV of -$1051.43/ha under the high price set. Under the high price set, the lowest mixed hardwood LEV yielded within the 3.5% - 7.5% ARR range was -$2387.05/ha. This minimum LEV represents a mixed hardwood plantation on a site class V site with high intensity site preparation, on an 80 year rotation, with an alternative rate of return of 7.5% (Table 43).

Under the high price set, the highest white pine LEV yielded within the 3.5% - 7.5% ARR range was $3746.65/ha. This maximum LEV represents a white pine plantation on a site class I site with medium intensity site preparation, on a 30 year rotation, with an alternative rate of return of 3.5% (Table 43). The base case scenario for white pine, represented by a 30 year rotation, a site class III site with medium intensity site preparation, and an alternative rate of return of 5% (Table 43), yields a LEV of -$78.32/ha under the high price set. Under the high price set, the lowest white pine LEV yielded within the 3.5% - 7.5% ARR range was -$2158.81/ha. This minimum LEV represents a white pine plantation on a site class V site with high intensity site preparation, on a 20 year rotation, with an alternative rate of return of 7.5% (Table 43).

As an example, under the high price assumption, in terms of LEV, an investment in a 30 year rotation white pine regime, under medium intensity site preparation on a site class III site, is worth $1129.75/ha more than a similar investment in a 60 year rotation mixed hardwood regime. Overall, under the high price assumption, the white pine scenarios yielded more positive LEVs than did the mixed hardwood scenarios. However, the highest and the lowest LEVs were yielded by mixed hardwood scenarios.

IV.4.1.D. Comparison of mixed hardwood and white pine incentive values

Incentives for the high price scenarios have been calculated for those scenarios corresponding to the high, base case and low LEVs, in order to estimate incentive ranges for both mixed hardwoods and white pine. These ranges of incentives are compared in Tables 44 - 47. The “high” incentive values correspond with the “low” LEVs, the “base case” incentive values correspond with the “base case” LEVs, and the “low” incentive values correspond with the “high” LEVs previously presented in Table 43.

Table 44 – Comparison of mixed hardwood and white pine lump sum payments (high prices)

Lump sum		Mixed hardwoods	White pine
High	*Lump sum ($/ha)*	**2387.05**	**2158.81**
	Rotation	80 years	20 years
	Site class	V	V
	Site preparation	High	High
	ARR	7.5%	7.5%
Base case	*Lump sum ($/ha)*	**1051.43**	**0**
	Rotation	60 years	*
	Site class	III	*
	Site preparation	Medium	*
	ARR	5%	*
Low	*Lump sum ($/ha)*	**0**	**0**
	Rotation	*	*
	Site class	*	*
	Site preparation	*	*
	ARR	*	*

As for the low price scenarios, any high price scenario that yields a positive LEV does not require an incentive in order to render the given scenario economically feasible. Hence, the incentive value given to all scenarios that yield positive LEVs is $0. Therefore, the value of $0 has been assigned to all the "low" mixed hardwood and white pine incentive values, and to all the "base case" white pine incentive values in the following tables of comparison.

High price scenario mixed hardwood lump sum payments, made at the time of planting, range from a minimum of $0/ha to a maximum of $2387.05/ha (Table 44). The corresponding range for mixed hardwood annual payments is $0/ha to $179.05/ha (Table 45). White pine lump sum payments, made at the time of planting, range from a minimum of $0/ha to a maximum of $2158.81/ha (Table 44). The corresponding range for white pine annual payments is $0/ha to $161.91/ha (Table 45). As an example, under scenarios that yield the minimum LEV for mixed hardwoods and white pine respectively, the incentive provider, in order to render a conversion to mixed hardwoods economically feasible, would have to offer the landowner a lump sum payment at planting that is $228.24/ha greater (or an annual payment that is $17.14/ha greater) than would be the case for a conversion to white pine.

Table 45 – Comparison of mixed hardwood and white pine annual payments (high prices)

Annual payment		Mixed hardwoods	White pine
High	*Annual payments ($/ha/year)*	**179.05**	**161.91**
	Rotation	80 years	20 years
	Site class	V	V
	Site preparation	High	High
	ARR	7.5%	7.5%
Base case	*Annual payments ($/ha/year)*	**52.57**	**0**
	Rotation	60 years	*
	Site class	III	*
	Site preparation	Medium	*
	ARR	5%	*
Low	*Annual payments ($/ha/year)*	**0**	**0**
	Rotation	*	*
	Site class	*	*
	Site preparation	*	*
	ARR	*	*

High price scenario mixed hardwood payments based on an increase in revenue at harvest range from a minimum of $0/ha to a maximum of $774824.73/ha (Table 46). White pine benefits based on an increase in revenue at harvest range from a minimum of $0/ha to a maximum of $7011.48/ha (Table 46). As an example, under scenarios that yield the minimum LEV for mixed hardwoods and white pine respectively, the incentive provider, in order to render a conversion to mixed hardwoods economically feasible, would have to offer the landowner a payment at harvest that is $767813.25/ha greater than would be the case for a conversion to white pine.

Table 46 – Comparison of mixed hardwood and white pine increase in revenue at harvest (high prices)

Revenue incentive		**Mixed hardwoods**	**White pine**
High	*Increase in revenue ($/ha)*	**774824.73**	**7011.48**
	Rotation	80 years	20 years
	Site class	V	V
	Site preparation	High	High
	ARR	7.5%	7.5%
Base case	*Increase in revenue ($/ha)*	**18588.37**	**0**
	Rotation	60 years	*
	Site class	III	*
	Site preparation	Medium	*
	ARR	5%	*
Low	*Increase in revenue ($/ha)*	**0**	**0**
	Rotation	*	*
	Site class	*	*
	Site preparation	*	*
	ARR	*	*

High price scenario mixed hardwood payments based on carbon volume range from a minimum of $0/ton of carbon to a maximum of $5.19/ton of carbon (Table 47). White pine benefits based on carbon volume range from a minimum of $0/ton of carbon to a maximum of $18.61/ton of carbon (Table 47). As an example, under scenarios that yield the minimum LEV for mixed hardwoods and white pine, respectively, the incentive provider, in order to render a conversion to mixed hardwoods economically feasible, would have to offer the landowner a carbon subsidy that is $13.42/ton of carbon less than would be the case for a conversion to white pine.

Table 47 – Comparison of mixed hardwood and white pine carbon payments (high prices)

Carbon payment		**Mixed hardwoods**	**White pine**
High	*Carbon payment ($/ton of carbon)*	**5.19**	**18.61**
	Rotation	80 years	20 years
	Site class	V	V
	Site preparation	High	High
	ARR	7.5%	7.5%
Base case	*Carbon payment ($/ton of carbon)*	**1.12**	**0**
	Rotation	60 years	*
	Site class	III	*
	Site preparation	Medium	*
	ARR	5%	*
Low	*Carbon payment ($/ton of carbon)*	**0**	**0**
	Rotation	*	*
	Site class	*	*
	Site preparation	*	*
	ARR	*	*

IV.4.1.E. Summary

A few important points can be highlighted from the high price scenario results. Naturally, all mixed hardwood and white pine LEVs increased from the low price scenarios, while incentive values decreased from the low price scenarios. A number of mixed hardwood scenarios become financially feasible, given the increase in product prices. These financially feasible mixed hardwood scenarios all fall within the 3.5% - 5% range of alternative rate of return. For the 3.5% alternative rate of return, all mixed hardwood scenarios with a rotation age of 50 years or shorter become financially feasible. Furthermore, other scenarios that become financially feasible are primarily those on good quality sites (site class I, II and III), under medium and low intensity site preparation. The number of financially feasible white pine scenarios increases from the low price scenarios. However, all financially feasible white pine scenarios still fall within the 3.5% - 5% range of alternative rate of return. The "base case LEV" for white pine increases by approximately 125%, with the product price increase. The "high LEV" for white pine increases by approximately 39%, with the product price increase. These significant increases in white pine LEV, associated with the product prices increase, highlight the financial benefits of selling timber in a niche market.

IV.5. Costs assumed by landowner versus costs assumed by coal company

According to the SMCRA requirements, mine operators are responsible for reclaiming mined land. Until recently, mine operators got away with reclaiming previously forested land to hayland/pasture and wildlife habitat. This left the landowner with the option of converting these reclaimed mined lands to forests at a later stage. Such a land-use conversion, however, comes at a substantial cost to the landowner, which makes the financial feasibility of such a conversion a questionable issue. This entire study is based upon the assumption that the landowner assumes the costs of converting land from its current use to forests. For the purposes of this study, this assumption is typically true, given that the land that is to undergo a land use conversion is reclaimed mined land for which the current landowner, and not the mine operator, is now responsible. However, as the law is progressively improved upon, reclamation practices by mine operators are being more tightly regulated and more closely monitored. Thus, land that was forested prior to mining is now required by law to be reforested after mining, which means that, unlike in the past, mine operators will now bare the burden of the reforestation costs, and not the landowners. Such a scenario would require that the mine operator be responsible for establishment of the forest, and that costs involved with establishment of the forest be born by the coal company, until bond release is achieved. Now, the landowner would be handed an established forest, for which he/she has not had to incur any establishment costs, which would mean that he/she simply benefits from the revenue received from sawtimber and pulpwood sales at harvest. This proposed scenario differs somewhat between hardwood and pine forests. It is assumed that the mixed hardwood stands will regenerate naturally, and thus, there will be no further establishment costs subsequent to the initial establishment costs. It is assumed, however, that the pine stands will be harvested at rotation age, and replanted, and thus there will be associated establishment costs at the beginning of each new rotation. The landowner will assume these costs, subsequent to the first rotation. The assumption that the coal company bears the costs of forest establishment has significant implications for the landowner in terms of the economic profitability of forestry as a post-mining land-use option. These economic implications will be briefly discussed for both mixed hardwood and white pine scenarios.

Hardwoods

LEVs for mixed hardwood scenarios, under the assumption that the coal company bears the costs of reforestation, and under the assumptions of a 60 year rotation, an alternative rate of return of 5% and low prices, are presented in Table 48. It is assumed that mixed hardwood stands will regenerate naturally after the first rotation, and hence, the LEVs presented in Tables 48 and 51 are calculated under the assumption of zero reforestation costs, subsequent to the first rotation.

Table 48 – Mixed hardwood LEVs (coal company assumes costs) - $/ha – (60 year rotation, 5% ARR, low prices)

	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	200.13	231.36	267.47
4	231.36	267.47	335.60
3	267.47	335.60	387.98
2	330.77	382.39	411.15
1	382.39	411.15	411.15

Trends displayed by low price mixed hardwood LEVs of scenarios in which the landowner assumes the costs of forest establishment (Table 24) have been discussed previously. Some of the trends displayed by LEVs of scenarios in which the coal company assumes the costs of forest establishment (Table 48) differ from those in which the landowner assumes the costs of forest establishment. LEV still increases steadily when moving from poorer quality sites (site class V) to better quality sites (site class I).

However, LEV now also increases steadily with increasing intensity of site preparation. This increase in LEV with increasing intensity of site preparation can be attributed to the fact that, for the landowner, there is no associated increase in costs of forest establishment with increasing intensity of site preparation, but rather an improvement in site quality, and hence, increased volumes and revenues at harvest.

Table 49 – Comparison of mixed hardwood LEV ranges for scenario where landowner assumes reforestation costs vs. where coal company assumes reforestation costs (low prices)

LEV		Mixed hardwoods (landowner assumes costs)	Mixed hardwoods (coal company assumes costs)
Low	*LEV ($/ha)*	**-2416.71**	**15.38**
	Rotation	80 years	80 years
	Site class	V	V
	Site preparation	High	High
	ARR	7.5%	7.5%
Base case	*LEV ($/ha)*	**-1710.16**	**335.60**
	Rotation	60 years	60 years
	Site class	III	III
	Site preparation	Medium	Medium
	ARR	5%	5%
High	*LEV ($/ha)*	**-145.58**	**2057.96**
	Rotation	40 years	40 years
	Site class	I	I
	Site preparation	Low	Low
	ARR	3.5%	3.5%

Table 49 shows some of the economic implications of changing the assumption that the landowner assumes the costs of forest establishment to the assumption that the coal company assumes these costs, for the low price scenarios. For example, for the "base case" scenario, mixed hardwood LEV increases by $2045.76/ha in favor of the landowner, when the assumption changes from the landowner assuming the costs of forest establishment to the coal company assuming these costs.

LEVs for mixed hardwood scenarios, under the assumption that the landowner bears the costs of reforestation, and under the assumptions of a 60 year rotation, an alternative rate of return of 5% and high prices, are presented in Table 50. LEVs for mixed hardwood scenarios, under the assumption that the coal company bears the costs of reforestation, and under the assumptions of a 60 year rotation, an alternative rate of return of 5% and high prices, are presented in Table 51. Trends displayed by high price LEVs of scenarios in which the coal company assumes the costs of forest establishment (Table 51) are similar to those displayed by the corresponding low price scenarios.

Table 50 – Mixed hardwood LEVs (landowner assumes costs) - $/ha – (60 year rotation, 5% ARR, high prices)

	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	-1146.60	-1368.46	-1801.39
4	-1055.17	-1262.75	-1590.06
3	-949.46	-1051.43	-1434.87
2	-752.45	-912.79	-1366.22
1	-599.50	-827.59	-1366.22

Table 51 – Mixed hardwood LEVs (coal company assumes costs) - $/ha – (60 year rotation, 5% ARR, high prices)

	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	585.87	677.30	783.01
4	677.30	783.01	994.34
3	783.01	994.34	1149.52
2	980.02	1132.97	1218.18
1	1132.97	1218.18	1218.18

Table 52 shows some of the economic implications of changing the assumption that the landowner assumes the costs of forest establishment to the assumption that the coal company assumes these costs, for the high price scenarios. For example, for the "low LEV" scenario, mixed hardwood LEV increases by $2432.09/ha in favor of the landowner, when the assumption changes from the landowner assuming the costs of forest establishment to the coal company assuming these costs.

Table 52 – Comparison of mixed hardwood LEV ranges for scenario where landowner assumes reforestation costs vs. where coal company assumes reforestation costs (high prices)

LEV		**Mixed hardwoods (landowner assumes costs)**	**Mixed hardwoods (coal company assumes costs)**
Low	*LEV ($/ha)*	**-2387.05**	**45.04**
	Rotation	80 years	80 years
	Site class	V	V
	Site preparation	High	High
	ARR	7.5%	7.5%
Base case	*LEV ($/ha)*	**-1051.43**	**994.34**
	Rotation	60 years	60 years
	Site class	III	III
	Site preparation	Medium	Medium
	ARR	5%	5%
High	*LEV ($/ha)*	**3955.72**	**6555.98**
	Rotation	40 years	40 years
	Site class	I	I
	Site preparation	Medium	Medium
	ARR	3.5%	3.5%

White pine

LEVs for white pine scenarios, under the assumption that the coal company bears the initial costs of reforestation, and under the assumptions of a 30 year rotation, an alternative rate of return of 5% and low prices, are presented in Table 53. It is assumed that white pine stands will be replanted subsequent to harvesting at the end of each rotation. Hence, all reforestation costs incurred, subsequent to the beginning of the second rotation, will be assumed by the landowner. Therefore, the LEVs presented in Tables 53 and 56 are calculated under the assumption that the landowner assumes all reforestation costs incurred subsequent to the end of the first rotation. These reforestation costs are the same as those referred to in Tables 17 and 18, but do not include ripping costs, as it is assumed that ripping will only be necessary at the beginning of the first rotation.

Table 53 – White pine LEVs (coal company assumes costs) - $/ha – (30 year rotation, 5% ARR, low prices)

	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	439.83	633.26	714.30
4	651.12	889.41	1482.05
3	889.41	1635.51	1929.32
2	1601.99	2042.13	2422.26
1	2042.14	2575.72	2730.14

Trends displayed by low price white pine LEVs of scenarios in which the landowner assumes the costs of forest establishment (Table 25) have been discussed previously. Some of the trends displayed by LEVs of scenarios in which the coal company assumes the costs of forest establishment (Table 53) differ from those in which the landowner assumes the costs of forest establishment. LEV still increases steadily when moving from poorer quality sites (site class V) to better quality sites (site class I). However, LEV now also increases steadily with increasing intensity of site preparation. As for the mixed hardwoods, this increase in LEV with increasing intensity of site preparation can be attributed to the fact that, for the landowner, there is no associated increase in costs of forest establishment with increasing intensity of site preparation, but rather an improvement in site quality, and hence, increased volumes and revenues at harvest.

Table 54 – Comparison of white pine LEV ranges for scenario where landowner assumes reforestation costs vs. where coal company assumes reforestation costs (low prices)

LEV		**White pine (landowner assumes costs)**	**White pine (coal company assumes costs)**
Low	*LEV ($/ha)*	**-2330.53**	**220.93**
	Rotation	20 years	20 years
	Site class	V	V
	Site preparation	High	High
	ARR	5%	5%
Base case	*LEV ($/ha)*	**-316.06**	**1635.51**
	Rotation	30 years	30 years
	Site class	III	III
	Site preparation	Medium	Medium
	ARR	5%	5%
High	*LEV ($/ha)*	**2697.98**	**4731.66**
	Rotation	30 years	30 years
	Site class	I	I
	Site preparation	Medium	Medium
	ARR	3.5%	3.5%

Table 54 shows some of the economic implications of changing the assumption that the landowner assumes the costs of forest establishment to the assumption that the coal company assumes these costs, for the low price scenarios. For example, for the "base case" scenario, white pine LEV increases by $1951.57/ha in favor of the landowner, when the assumption changes from the landowner assuming the costs of forest establishment to the coal company assuming these costs.

LEVs for white pine scenarios, under the assumption that the landowner bears the costs of reforestation, and under the assumptions of a 30 year rotation, an alternative rate of return of 5% and high prices, are presented in Table 55. LEVs for white pine scenarios, under the assumption that the coal company bears the costs of reforestation, and under the assumptions of a 30 year rotation, an alternative rate of return of 5% and high prices, are presented in Table 56. Trends displayed by high price LEVs of scenarios in which the coal company assumes the costs of forest establishment (Table 56) are similar to those displayed by the corresponding low price scenarios.

Table 55 – White pine LEVs (landowner assumes costs) - $/ha – (30 year rotation, 5% ARR, high prices)

	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	-926.98	-1077.09	-1454.64
4	-669.54	-764.99	-584.94
3	-379.21	78.32	-53.95
2	424.29	561.05	531.27
1	946.83	1194.52	896.78

Table 56 – White pine LEVs (coal company assumes costs) - *$/ha – (30 year rotation, 5% ARR, high prices)*

	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	638.81	874.48	1006.73
4	896.25	1186.58	1876.43
3	1186.58	2029.89	2407.42
2	1990.09	2512.62	2992.63
1	2512.63	3146.09	3358.14

Table 57 – Comparison of white pine LEV ranges for scenario where landowner assumes reforestation costs vs. where coal company assumes reforestation costs (high prices)

LEV		**White pine (landowner assumes costs)**	**White pine (coal company assumes costs)**
Low	*LEV ($/ha)*	**-2158.81**	**283.18**
	Rotation	20 years	20 years
	Site class	V	V
	Site preparation	High	High
	ARR	7.5%	7.5%
Base case	*LEV ($/ha)*	**78.32**	**2029.89**
	Rotation	30 years	30 years
	Site class	III	III
	Site preparation	Medium	Medium
	ARR	5%	5%
High	*LEV ($/ha)*	**3746.65**	**5780.34**
	Rotation	30 years	30 years
	Site class	I	I
	Site preparation	Medium	Medium
	ARR	3.5%	3.5%

Table 57 shows the economic implications of changing the assumption that the landowner assumes the costs of forest establishment to the assumption that the coal company assumes these costs, for the high price scenarios. For example, for the "high

LEV" scenario, white pine LEV increases by $2033.69/ha in favor of the landowner, when the assumption changes from the landowner assuming the costs of forest establishment to the coal company assuming these costs.

It is evident that (for both the low and the high price scenarios), under the assumption that the coal company assumes the costs of reforestation, all of the proposed mixed hardwood and white pine scenarios yielded positive LEVs, which would suggest that all of these scenarios are economically feasible. Therefore, there is no need for incentives.

IV.5.1. Summary

From the standpoint of a landowner, it would obviously be preferable, from a financial point of view, to leave initial site preparation and reforestation up to the coal company, and in so doing, spare the landowner the initial costs of reclaiming the mined land. The risk in leaving this reforestation responsibility up to the coal company is the possibility of a half-hearted attempt at reforesting the land, due to the coal company having no long-term interests in the future uses of the mined land. Were the coal company to assume the costs of reclaiming the mined lands, from a landowner's perspective, it would now be most profitable to invest in high intensity site preparation on the best quality sites. However, in reality, the coal company would seek to reclaim the mined land in such a way that bond release is achieved at the least cost possible. This least cost option would most likely entail low intensity site preparation, regardless of site quality or other market factors. As an example of how this least cost reforestation scenario (coal company assumes costs) would impact the landowner economically, mixed hardwood LEV on a site class I site, under low intensity site preparation (rotation age 60 years, 5% ARR, low prices) would increase by approximately 164% from the corresponding scenario in which the landowner assumed the costs of reforestation. Thus, under this least cost reforestation scenario, the landowner (who assumes no costs) would still come out the winner.

CHAPTER V – CONCLUSIONS

V.1. Introduction

It must once again be emphasized that the purpose of this study was not to determine the perfect land-use-conversion scenario, or to calculate land expectation values and incentive values upon which landowners should base financial decisions. The primary purpose of this study was to develop a framework for calculating/understanding the economic implications of converting reclaimed mined lands to forests, and the incentives that would be required to render these land-use-conversion regimes profitable for the landowners. This framework is ultimately aimed at assisting landowners in the land-use-conversion decision-making process. Furthermore, it was the purpose of this study to identify trends in the calculated LEVs and incentive values, based on species type, rotation age, alternative rate of return, site quality, site preparation intensity, and product prices. At the same time, broad ranges of LEVs and incentive values were estimated for the conversion of reclaimed mined lands to forests.

V.2. Framework

The framework developed for this study, for the assessment of the economic feasibility of converting reclaimed mined lands from their current use to forests, comprised a few key steps. Firstly, data from reclaimed mined lands were used to estimate forest stand growth and yield equations for both mixed hardwoods and white pine. Secondly, costs were estimated for the three proposed levels of site preparation intensity. Thirdly, LEVs were calculated for both mixed hardwoods and white pine, over a broad spectrum of land-use conversion scenarios. These scenarios differed according to rotation age, alternative rate of return, initial site quality, site preparation intensity, and product prices. Based on these calculated LEVs, trends were evaluated in an effort to identify which scenarios tend to be most profitable and which scenarios tend to be least profitable to the landowner. Further, three types of incentives were investigated, each with the common objective of rendering a land-use conversion profitable for a landowner. The three incentive schemes were: 1) lump sum payment at planting (and equivalent series of annual payments), 2) revenue incentive at harvest and 3) benefit based on carbon volume. Incentive values were then calculated for a subset of scenarios, including those scenarios corresponding to the most profitable and least profitable land-use conversion scenarios for both mixed hardwoods and white pine. The primary purpose of calculating a benefit based on carbon volume was to determine a range of potential carbon values i.e., to give us an idea of how much carbon is worth under various land-use conversion conditions.

V.3. Summary of findings

Given the number of variables involved in the economic feasibility assessment, it is nearly impossible to identify one correct or best solution. Based on some of the trends that have been identified, however, it is possible to identify a few land use conversion regimes that would potentially be the most profitable or least profitable for the landowner. The mixed hardwood and white pine results share a few general trends, but also differ significantly in some areas.

V.3.1. Mixed hardwood LEVs

An optimal rotation length for mixed hardwoods has not been identified in this study. The results suggested a particularly short optimal rotation length (20 years – outside of proposed rotation range) for mixed hardwoods. It is suspected that this short rotation length is primarily due to the fact that varying product ratios with rotation length were not taken into account. This is noted as a limitation to this study. As would be expected, for a given site preparation intensity, results suggest that mixed hardwood LEVs tend to increase when moving from poorer quality sites to better quality sites. Results suggest a trend of decreasing mixed hardwood LEV with increasing intensity of site preparation, and hence, minimal site preparation seems advisable for most mixed hardwood regimes. Consistent over all site classes, all site preparation intensities, and all rotation ages, is the trend of decreasing LEV with increasing alternative rate of return. Therefore, in short, were a landowner to be set on planting mixed hardwoods, in general it would be most profitable for him/her to invest in such a land-use conversion on the best quality sites (site class I), with low intensity site preparation, and with the lowest alternative rate of return possible. This finding is in keeping with those conclusions made by Kronrad et al. (2002). Results for the high price set did suggest, however, that on shorter rotations (less than 50 years), mixed hardwood LEV was maximized under medium intensity site preparation. Results also suggest that, were a landowner to be set on planting mixed hardwoods, in general it would be least profitable for him/her to invest in such a land-use conversion on poor quality sites (site class V), especially under high intensity site preparation, a high alternative rate of return, and on a long rotation (80 years).

V.3.2. White pine LEVs

Results suggest an optimal white pine rotation age range of 25 – 35 years for the low price set. This range decreases to approximately 25 – 30 years for the high price set. As for them mixed hardwood LEVs, white pine LEVs tend to increase when moving from poorer quality sites to better quality sites. White pine results suggest that LEV is maximized on site classes I, II and III under medium intensity site preparation, and that LEV is maximized on site classes IV and V under low intensity site preparation. This trend does depend, however, on the alternative rate of return, as optimal intensity of site preparation tends to increase with decreasing alternative rate of return for white pine scenarios. As with the mixed hardwoods, the trend of decreasing white pine LEV with increasing alternative rate of return is consistent over all site classes, all site preparation intensities, and all rotation ages. White pine results also suggest that the optimal intensity of site preparation and the optimal rotation age both decrease as the alternative rate of return increases. Therefore, in short, were a landowner to be set on planting white pine, in general it would be most profitable for him/her to invest in such a land-use conversion on the best quality sites (site class I), with medium intensity site preparation, on a rotation of approximately 30 years, and with the lowest alternative rate of return possible. Results also suggest that, were a landowner to be set on planting white pine, in general it would be least profitable for him/her to invest in such a land-use conversion on poor quality sites (site class V), especially under high intensity site preparation, a high alternative rate of return, and on a short rotation (20 years).

V.3.3. Comparison of mixed hardwood and white pine LEVs

Under the low price set, the mixed hardwood results yielded a LEV range of -\$2416.71/ha to -\$145.58/ha. Under the low price set, the white pine results yielded a LEV range of -\$2330.43/ha to \$2697.98/ha. Thus, it would appear that, under the low price set, planting white pine on reclaimed mine lands could be profitable for the landowner under a number of different reforestation regimes, whereas converting the land to mixed hardwood plantations does not offer the landowner any profitable options. These LEV ranges change significantly under the set of high prices. Under the high price set, the mixed hardwood results yielded a LEV range of -\$2387.05/ha to \$3955.72/ha. Under the high price set, the white pine results yielded a LEV range of -\$2158.81/ha to \$3746.65/ha. These LEV ranges for the high price set are much more similar for mixed hardwoods and white pine than those for the low price set. Under the high price set, the number of white pine reforestation regimes that appear to be economically feasible (positive LEVs) still outnumber economically feasible mixed hardwood regimes. However, given these high prices, converting land to mixed hardwood plantations now offers a number of economically profitable options, the most profitable of which is slightly more profitable than the most profitable white pine scenario. Thus, given the product price increase, it appears that the decision to convert land to mixed hardwood plantations versus converting the land to white pine plantations becomes less significant for scenarios yielding the highest and the lowest LEVs for both mixed hardwood and white pine scenarios. In general, the higher prices make a land-use conversion on lower site classes feasible for both mixed hardwoods and white pine. Given that Sullivan et al. (2003) show the average sale price per hectare of forested land in Southwest Virginia to be approximately \$1259.67/ha, a number of the more profitable land-use conversion scenarios for both mixed hardwoods and white pine in this study (particularly for the high price set) yield LEVs that suggest a comparable sales price for bare land.

V.3.4. Incentives

As expected, the incentive values calculated for both mixed hardwood and white pine scenarios display trends that are exactly the opposite of those displayed by the LEVs of the corresponding scenarios. Useful for the policy maker are the incentive value ranges calculated for this study.

V.3.4.A. Comparison of mixed hardwood and white pine lump sum payments at planting (and corresponding series of annual payments)

Mixed hardwoods lump sum payments, made at the time of planting, range from a minimum of \$0/ha to a maximum of \$2416.71/ha (low prices). The corresponding range for mixed hardwood annual payments is \$0/ha to \$181.25/ha. White pine lump sum payments, made at the time of planting, range from a minimum of \$0/ha to a maximum of \$2330.53/ha (low prices). The corresponding range for white pine annual payments is \$0/ha to \$161.91/ha (high prices). Based on these incentive ranges, it would appear that, although the white pine option renders somewhat lower incentive ranges, incentive providers could expect to offer similar lump sum payments (or annual payments) to landowners converting to mixed hardwoods or white pine options, especially for the least profitable scenarios.

V.3.4.B. Comparison of mixed hardwood and white pine revenue incentives at harvest

Mixed hardwoods benefits based on an increase in revenue at harvest, range from a minimum of $0/ha to a maximum of $784449.52/ha (low prices). It must be noted that this maximum mixed hardwood revenue incentive at harvest occurs under the extreme, and somewhat unlikely conditions of an 80 year rotation and an alternative rate of return of 7.5%. White pine benefits based on an increase in revenue at harvest, range from a minimum of $0/ha to a maximum of $7011.48/ha (high prices). There is a huge difference between these mixed hardwood and white pine maximum incentive values based on an increase in revenue at harvest. However, it must be pointed out that It would seem likely that an incentive provider would not be inclined to offer a landowner a payment at harvest of anything near the magnitude of the maximum payment calculated for the mixed hardwood scenarios. Were this to be the type of incentive offered to landowners, it would seem probable that incentive providers would be more inclined to offer financial assistance to landowners converting to white pine plantations.

V.3.4.C. Comparison of mixed hardwood and white pine payments based on carbon volume

Annual mixed hardwood benefits, based on total stand carbon volume present at the end of a given year, range from a minimum of $0/ton of carbon to a maximum of $5.26/ton carbon (low prices). White pine benefits based on carbon volume range from a minimum of $0/ton of carbon to a maximum of $18.61/ton of carbon (high prices). The higher maximum white pine carbon payment can primarily be attributed to the fact that the shorter rotation means that payments for white pine carbon are being made on far less cumulative carbon tonnage than for that of the long rotation hardwoods. Therefore, the payment per ton of white pine carbon needs to be higher than that of the hardwoods, in order to render the conversion to white pine profitable by the end of a rotation. These carbon payments may seem appealingly low to the incentive provider. However, payments (not discounted) made over a full rotation may sum up to approximately \$17493/ha for white pine (30 year rotation), and \$18820/ha for mixed hardwoods (60 year rotation). The literature suggests a range of carbon sequestration costs, from \$0/ton of carbon to \$120/ton of carbon, although the majority of studies suggest a cost below \$50/ ton of carbon, with van Kooten et al. (2000) suggesting a cut-off cost of \$20/ton of carbon sequestered. Thus, the ranges of carbon payments estimated for this study fall well within the ranges of carbon sequestration costs estimated in previous studies.

V.4. Value of this study

It seems that this study is the first of its kind to be based on actual mined land growth and yield data. The economic analysis conducted in this study is also based on silvicultural prescriptions that are specifically designed for mined sites. Different to other studies, this study considers both mixed hardwood and white pine forests as land-use conversion options. More than anything, this study provides a basic framework for assessing the economic implications of converting reclaimed mined lands to forests, and the incentives that may be necessary in encouraging landowners to undertake such land-use conversions. This framework offers landowners and policy makers a foundation upon which the decision-making process (to convert land) can be built. The LEV and incentive value trends and ranges estimated in this study should go towards assisting both the landowner and the policy-maker in their decisions to undertake a land-use conversion and to provide incentives respectively. This study will add to the limited literature available, pertaining to the economic implications of converting reclaimed mined lands to forests, for the primary purpose of sequestering carbon, and pertaining to the use of incentive schemes to encourage this land-use conversion.

V.5. Limitations/Future research

The primary limitation to this study was the limited range of case study data, on which our economic analysis was based. This may affect the results, especially when input data is outside of the range of data upon which the model was built. Being one of the first studies of its kind, a secondary limitation has been the lack of real data to which the accuracy of the model can be directly compared. The framework developed in this study for examining the economic feasibility of converting reclaimed mined lands to forests, and the potential for incentive schemes, provides the groundwork for future policy-related research, addressing such land-use conversions. Future research related to this study could be aimed at refining the model upon which this study was based. This could be done by improving on the assumptions made for this study, and by examining in more detail the interrelations between all the variables involved in this economic analysis.

Part of this refining/improvement process should include the incorporation of varying product ratios with rotation age, and perhaps the incorporation of amenity values associated with forests. These varying product ratios with rotation age are difficult to estimate accurately, for a number of reasons. In considering hardwood products, it is necessary to take into account, not only the size of trees, but also species, and bole form.

With limited growth and yield models available for mixed Appalachian hardwood stands, accurate prediction of some of these factors becomes very difficult. A number of different amenity values could be factored into LEV and incentive value calculations. One such amenity value, which has in recent years received a lot of attention, is the flood control benefit associated with forests. Incorporating this and many other amenity values into the economic feasibility analysis would ultimately result in an increase in LEVs and a decrease in incentive values, thus rendering more land-use conversion scenarios economically feasible. For policy-makers, a broader spectrum of potential incentive schemes may be an important area for future research. Furthermore, it will be important in the future to compare the results of this research to case study data. Based on these comparisons, and the ever-increasing pool of input and output data that becomes available, it will be possible to improve upon the framework developed in this study for analyzing the economic feasibility of converting reclaimed mined lands to forests.

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Appendix A – Mixed hardwood and white pine LEVs and NPVs

Mixed hardwood and white pine LEVs ($/ha) and NPVs ($/ha):

- 3.5% ARR
- low price set
- hardwood rotation = 40 years
- white pine rotation = 20 years

LEV - HDWDS	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1126.51	-1355.14	-1851.30
4	-958.42	-1160.82	-1484.60
3	-764.10	-794.12	-1202.72
2	-423.41	-542.30	-1078.01
1	-145.58	-387.53	-1078.01

LEV - Pine	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1484.37	-1724.25	-2329.91
4	-1095.26	-1252.53	-916.04
3	-656.43	121.45	-92.37
2	655.80	870.26	815.40
1	1466.36	1852.90	1382.38

NPV - HDWDS	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-841.99	-1012.87	-1383.71
4	-716.35	-867.63	-1109.63
3	-571.11	-593.55	-898.95
2	-316.47	-405.33	-805.74
1	-108.81	-289.65	-805.74

NPV - Pine	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-738.38	-857.70	-1158.97
4	-544.82	-623.05	-455.67
3	-326.53	60.41	-45.95
2	326.22	432.90	405.61
1	729.42	921.69	687.64

Mixed hardwood and white pine LEVs ($/ha) and NPVs ($/ha):

- 3.5% ARR
- low price set
- hardwood rotation = 50 years
- white pine rotation = 25 years

LEV - HDWDS	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1266.51	-1512.25	-2007.44
4	-1151.06	-1378.79	-1755.59
3	-1017.60	-1126.95	-1562.00
2	-783.62	-954.00	-1476.35
1	-592.81	-847.70	-1476.35

LEV - Pine	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-983.25	-1127.10	-1572.99
4	-578.88	-636.90	-103.73
3	-122.87	790.93	752.21
2	1240.79	1569.08	1695.56
1	2083.11	2590.21	2284.75

NPV - HDWDS	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1039.73	-1241.48	-1648.00
4	-944.96	-1131.92	-1441.25
3	-835.40	-925.16	-1282.32
2	-643.31	-783.18	-1212.00
1	-486.66	-695.92	-1212.00

NPV - Pine	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-567.19	-650.17	-907.39
4	-333.93	-367.40	-59.84
3	-70.88	456.25	433.92
2	715.75	905.13	978.09
1	1201.65	1494.17	1317.96

Mixed hardwood and white pine LEVs ($/ha) and NPVs ($/ha):

- 3.5% ARR
- low price set
- hardwood rotation = 60 years
- white pine rotation = 30 years

LEV - HDWDS	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1372.05	-1631.40	-2129.71
4	-1291.77	-1538.59	-1954.57
3	-1198.96	-1363.46	-1819.94
2	-1036.24	-1243.19	-1760.38
1	-903.55	-1169.27	-1760.38

LEV - Pine	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-768.42	-873.41	-1243.99
4	-379.93	-402.45	167.60
3	58.18	969.32	989.94
2	1368.31	1716.93	1896.26
1	2177.56	2697.98	2462.32

NPV - HDWDS	**Site preparation intensity**		
Site class	***Low***	***Medium***	***High***
5	-1197.89	-1424.32	-1859.37
4	-1127.80	-1343.29	-1706.47
3	-1046.77	-1190.39	-1588.93
2	-904.71	-1085.38	-1536.93
1	-788.86	-1020.85	-1536.93

NPV - Pine	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-494.65	-562.23	-800.78
4	-244.57	-259.07	107.89
3	37.45	623.97	637.25
2	880.81	1105.22	1220.66
1	1401.74	1736.75	1585.05

Mixed hardwood and white pine LEVs ($/ha) and NPVs ($/ha):

- 3.5% ARR
- low price set
- hardwood rotation = 70 years
- white pine rotation = 35 years

LEV - HDWDS	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1449.03	-1718.56	-2220.57
4	-1392.72	-1653.45	-2097.72
3	-1327.61	-1530.61	-2003.29
2	-1213.48	-1446.24	-1961.51
1	-1120.40	-1394.39	-1961.51

LEV - Pine	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-702.85	-798.60	-1138.40
4	-344.74	-364.46	162.83
3	59.13	900.07	920.88
2	1266.83	1589.23	1756.34
1	2012.81	2493.58	2278.15

NPV - HDWDS	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1318.64	-1563.91	-2020.75
4	-1267.39	-1504.67	-1908.96
3	-1208.15	-1392.87	-1823.02
2	-1104.28	-1316.10	-1785.00
1	-1019.58	-1268.92	-1785.00

NPV - Pine	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-492.01	-559.04	-796.91
4	-241.32	-255.13	113.99
3	41.39	630.07	644.64
2	886.81	1112.50	1229.48
1	1409.02	1745.56	1594.76

Mixed hardwood and white pine LEVs ($/ha) and NPVs ($/ha):

- 3.5% ARR
- low price set
- hardwood rotation = 80 years
- white pine rotation = 40 years

LEV - HDWDS	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1504.63	-1781.63	-2286.94
4	-1464.90	-1735.69	-2200.27
3	-1418.97	-1649.02	-2133.64
2	-1338.44	-1589.49	-2104.16
1	-1272.77	-1552.91	-2104.16

LEV - Pine	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-714.69	-816.34	-1149.11
4	-392.37	-425.59	22.06
3	-28.87	712.54	704.34
2	1058.12	1332.82	1456.30
1	1729.54	2146.78	1925.95

NPV - HDWDS	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1408.65	-1667.97	-2141.05
4	-1371.45	-1624.97	-2059.90
3	-1328.45	-1543.82	-1997.53
2	-1253.06	-1488.09	-1969.93
1	-1191.57	-1453.84	-1969.93

NPV - Pine	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-534.18	-610.15	-858.87
4	-293.27	-318.10	16.49
3	-21.58	532.58	526.45
2	790.87	996.19	1088.48
1	1292.71	1604.56	1439.51

Mixed hardwood and white pine LEVs ($/ha) and NPVs ($/ha):

- 5% ARR
- low price set
- hardwood rotation = 40 years
- white pine rotation = 20 years

LEV - HDWDS	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1383.52	-1646.77	-2145.76
4	-1301.16	-1551.56	-1966.10
3	-1205.95	-1371.90	-1828.00
2	-1039.03	-1248.53	-1766.90
1	-902.91	-1172.70	-1766.90

LEV - Pine	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1508.30	-1770.91	-2330.53
4	-1275.35	-1488.51	-1484.08
3	-1012.64	-665.94	-990.97
2	-227.03	-217.64	-447.51
1	258.23	370.64	-108.07

NPV - HDWDS	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1186.99	-1412.86	-1840.97
4	-1116.34	-1331.17	-1686.83
3	-1034.65	-1177.03	-1568.34
2	-891.44	-1071.18	-1515.92
1	-774.66	-1006.12	-1515.92

NPV - Pine	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-939.84	-1103.48	-1452.18
4	-794.68	-927.50	-924.75
3	-630.98	-414.95	-617.48
2	-141.47	-135.61	-278.85
1	160.91	230.95	-67.34

Mixed hardwood and white pine LEVs ($/ha) and NPVs ($/ha):

- 5% ARR
- low price set
- hardwood rotation = 50 years
- white pine rotation = 25 years

LEV - HDWDS	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1472.37	-1746.65	-2246.69
4	-1421.80	-1688.19	-2136.38
3	-1363.34	-1577.88	-2051.58
2	-1260.85	-1502.12	-2014.06
1	-1177.28	-1455.56	-2014.06

LEV - Pine	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1225.81	-1435.11	-1902.18
4	-994.81	-1155.08	-1062.83
3	-734.30	-339.41	-573.86
2	44.71	105.12	-34.96
1	525.90	688.46	301.62

NPV - HDWDS	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1343.97	-1594.34	-2050.77
4	-1297.82	-1540.98	-1950.08
3	-1244.46	-1440.28	-1872.67
2	-1150.90	-1371.13	-1838.43
1	-1074.61	-1328.63	-1838.43

NPV - Pine	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-863.82	-1011.32	-1340.46
4	-701.04	-813.98	-748.98
3	-517.46	-239.18	-404.40
2	31.51	74.08	-24.64
1	370.60	485.16	212.55

Mixed hardwood and white pine LEVs ($/ha) and NPVs ($/ha):

- 5% ARR
- low price set
- hardwood rotation = 60 years
- white pine rotation = 30 years

LEV - HDWDS	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	-1532.35	-1814.41	-2316.93
4	-1501.11	-1778.30	-2248.79
3	-1465.01	-1710.16	-2196.42
2	-1401.70	-1663.37	-2173.24
1	-1350.08	-1634.61	-2173.24

LEV - Pine	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	-1125.97	-1318.31	-1747.07
4	-914.67	-1062.16	-979.31
3	-676.38	-316.06	-532.05
2	36.19	90.56	-39.10
1	476.35	624.15	268.78

NPV - HDWDS	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	-1450.31	-1717.27	-2192.89
4	-1420.75	-1683.10	-2128.40
3	-1386.58	-1618.61	-2078.83
2	-1326.66	-1574.32	-2056.90
1	-1277.80	-1547.10	-2056.90

NPV - Pine	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	-865.44	-1013.29	-1342.84
4	-703.03	-816.40	-752.72
3	-519.88	-242.93	-408.94
2	27.82	69.61	-30.06
1	366.13	479.74	206.59

Mixed hardwood and white pine LEVs ($/ha) and NPVs ($/ha):

- 5% ARR
- low price set
- hardwood rotation = 70 years
- white pine rotation = 35 years

LEV - HDWDS	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1571.44	-1858.69	-2363.43
4	-1552.09	-1836.31	-2321.22
3	-1529.72	-1794.10	-2288.76
2	-1490.49	-1765.10	-2274.40
1	-1458.51	-1747.28	-2274.40

LEV - Pine	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1114.52	-1307.29	-1724.60
4	-929.46	-1082.95	-1052.20
3	-720.77	-429.52	-660.49
2	-96.71	-73.41	-228.78
1	288.77	393.90	40.86

NPV - HDWDS	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1519.80	-1797.60	-2285.76
4	-1501.08	-1775.96	-2244.93
3	-1479.44	-1735.13	-2213.54
2	-1441.51	-1707.09	-2199.65
1	-1410.57	-1689.86	-2199.65

NPV - Pine	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-912.46	-1070.29	-1411.95
4	-760.96	-886.62	-861.45
3	-590.10	-351.66	-540.75
2	-79.18	-60.10	-187.30
1	236.42	322.49	33.45

Mixed hardwood and white pine LEVs ($/ha) and NPVs ($/ha):

- 5% ARR
- low price set
- hardwood rotation = 80 years
- white pine rotation = 40 years

LEV - HDWDS	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1596.55	-1887.17	-2393.58
4	-1584.54	-1873.29	-2367.39
3	-1570.66	-1847.09	-2347.25
2	-1546.33	-1829.11	-2338.34
1	-1526.48	-1818.05	-2338.34

LEV - Pine	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1144.03	-1345.08	-1764.02
4	-986.12	-1153.63	-1190.21
3	-808.02	-596.01	-855.93
2	-275.46	-292.11	-487.51
1	53.50	106.68	-257.41

NPV - HDWDS	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1564.34	-1849.09	-2345.29
4	-1552.57	-1835.49	-2319.62
3	-1538.97	-1809.83	-2299.89
2	-1515.13	-1792.20	-2291.16
1	-1495.68	-1781.37	-2291.16

NPV - Pine	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-981.53	-1154.02	-1513.45
4	-846.04	-989.77	-1021.15
3	-693.25	-511.35	-734.35
2	-236.33	-250.62	-418.27
1	45.90	91.53	-220.85

Mixed hardwood and white pine LEVs ($/ha) and NPVs ($/ha):

- 7.5% ARR
- low price set
- hardwood rotation = 40 years
- white pine rotation = 20 years

LEV - HDWDS	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	-1536.74	-1821.47	-2316.95
4	-1507.55	-1787.73	-2253.29
3	-1473.81	-1724.07	-2204.35
2	-1414.66	-1680.34	-2182.69
1	-1366.43	-1653.47	-2182.69

LEV - Pine	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	-1521.46	-1800.72	-2322.93
4	-1402.88	-1656.97	-1892.05
3	-1269.15	-1238.24	-1641.03
2	-869.24	-1010.04	-1364.39
1	-622.22	-710.58	-1191.60

NPV - HDWDS	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	-1451.57	-1720.53	-2188.55
4	-1424.01	-1688.66	-2128.41
3	-1392.14	-1628.52	-2082.18
2	-1336.26	-1587.22	-2061.73
1	-1290.70	-1561.84	-2061.73

NPV - Pine	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	-1163.29	-1376.81	-1776.08
4	-1072.62	-1266.89	-1446.64
3	-970.37	-946.74	-1254.71
2	-664.61	-772.26	-1043.19
1	-475.74	-543.30	-911.08

Mixed hardwood and white pine LEVs ($/ha) and NPVs ($/ha):

- 7.5% ARR
- low price set
- hardwood rotation = 50 years
- white pine rotation = 25 years

LEV - HDWDS	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	-1579.48	-1869.57	-2366.37
4	-1564.86	-1852.66	-2334.46
3	-1547.95	-1820.76	-2309.94
2	-1518.31	-1798.85	-2299.08
1	-1494.13	-1785.38	-2299.08

LEV - Pine	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	-1392.88	-1648.58	-2126.53
4	-1284.76	-1517.50	-1733.66
3	-1162.82	-1135.72	-1504.79
2	-798.20	-927.65	-1252.55
1	-572.97	-654.61	-1095.01

NPV - HDWDS	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	-1537.01	-1819.30	-2302.74
4	-1522.78	-1802.85	-2271.69
3	-1506.33	-1771.80	-2247.82
2	-1477.48	-1750.48	-2237.26
1	-1453.96	-1737.37	-2237.26

NPV - Pine	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	-1164.48	-1378.25	-1777.82
4	-1074.08	-1268.66	-1449.38
3	-972.14	-949.48	-1258.04
2	-667.31	-775.53	-1047.16
1	-479.01	-547.26	-915.45

Mixed hardwood and white pine LEVs ($/ha) and NPVs ($/ha):

- 7.5% ARR
- low price set
- hardwood rotation = 60 years
- white pine rotation = 30 years

LEV - HDWDS	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	-1602.96	-1896.10	-2394.16
4	-1595.66	-1887.66	-2378.24
3	-1587.22	-1871.74	-2366.00
2	-1572.43	-1860.80	-2360.58
1	-1560.36	-1854.08	-2360.58

LEV - Pine	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	-1364.38	-1616.28	-2080.18
4	-1273.87	-1506.55	-1751.30
3	-1171.80	-1186.95	-1559.71
2	-866.56	-1012.77	-1348.55
1	-678.01	-784.20	-1216.67

NPV - HDWDS	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	-1582.05	-1871.36	-2362.93
4	-1574.84	-1863.04	-2347.21
3	-1566.52	-1847.32	-2335.13
2	-1551.91	-1836.53	-2329.79
1	-1540.01	-1829.89	-2329.79

NPV - Pine	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	-1208.54	-1431.67	-1842.58
4	-1128.37	-1334.47	-1551.27
3	-1037.95	-1051.38	-1381.56
2	-767.58	-897.09	-1194.52
1	-600.57	-694.63	-1077.70

Mixed hardwood and white pine LEVs ($/ha) and NPVs ($/ha):

- 7.5% ARR
- low price set
- hardwood rotation = 70 years
- white pine rotation = 35 years

LEV - HDWDS	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1615.33	-1910.12	-2409.00
4	-1611.71	-1905.92	-2401.08
3	-1607.51	-1898.01	-2395.00
2	-1600.16	-1892.57	-2392.31
1	-1594.16	-1889.23	-2392.31

LEV - Pine	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1377.12	-1633.14	-2096.08
4	-1304.88	-1545.57	-1833.60
3	-1223.42	-1290.50	-1680.69
2	-979.81	-1151.49	-1512.17
1	-829.33	-969.07	-1406.91

NPV - HDWDS	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1605.11	-1898.02	-2393.75
4	-1601.50	-1893.86	-2385.88
3	-1597.34	-1885.99	-2379.84
2	-1590.03	-1880.59	-2377.17
1	-1584.07	-1877.27	-2377.17

NPV - Pine	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1267.55	-1503.21	-1929.31
4	-1201.06	-1422.60	-1687.72
3	-1126.08	-1187.82	-1546.97
2	-901.85	-1059.87	-1391.86
1	-763.35	-891.97	-1294.98

Mixed hardwood and white pine LEVs ($/ha) and NPVs ($/ha):

- 7.5% ARR
- low price set
- hardwood rotation = 80 years
- white pine rotation = 40 years

LEV - HDWDS	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1621.71	-1917.35	-2416.71
4	-1619.92	-1915.27	-2412.79
3	-1617.84	-1911.35	-2409.77
2	-1614.20	-1908.66	-2408.44
1	-1611.23	-1907.01	-2408.44

LEV - Pine	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1404.14	-1666.83	-2133.94
4	-1348.18	-1598.98	-1930.60
3	-1285.07	-1401.38	-1812.14
2	-1096.34	-1293.69	-1681.59
1	-979.77	-1152.36	-1600.04

NPV - HDWDS	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1616.73	-1911.46	-2409.28
4	-1614.94	-1909.39	-2405.38
3	-1612.87	-1905.48	-2402.37
2	-1609.24	-1902.80	-2401.04
1	-1606.28	-1901.15	-2401.04

NPV - Pine	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1326.32	-1574.45	-2015.68
4	-1273.46	-1510.37	-1823.61
3	-1213.85	-1323.72	-1711.71
2	-1035.58	-1221.99	-1588.39
1	-925.47	-1088.50	-1511.37

Mixed hardwood and white pine LEVs ($/ha) and NPVs ($/ha):

- 10% ARR
- low price set
- hardwood rotation = 40 years
- white pine rotation = 20 years

LEV - HDWDS	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	-1581.91	-1873.89	-2362.64
4	-1570.67	-1860.90	-2338.12
3	-1557.68	-1836.38	-2319.28
2	-1534.90	-1819.54	-2310.94
1	-1516.32	-1809.19	-2310.94

LEV - Pine	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	-1522.95	-1809.68	-2311.38
4	-1455.71	-1728.16	-2067.04
3	-1379.87	-1490.72	-1924.70
2	-1153.10	-1361.32	-1767.83
1	-1013.02	-1191.50	-1669.85

NPV - HDWDS	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	-1546.96	-1832.49	-2310.44
4	-1535.97	-1819.78	-2286.46
3	-1523.26	-1795.80	-2268.03
2	-1500.99	-1779.34	-2259.88
1	-1482.82	-1769.22	-2259.88

NPV - Pine	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	-1296.57	-1540.68	-1967.81
4	-1239.32	-1471.28	-1759.79
3	-1174.76	-1269.13	-1638.61
2	-981.70	-1158.96	-1505.05
1	-862.44	-1014.39	-1421.63

Mixed hardwood and white pine LEVs ($/ha) and NPVs ($/ha):

- 10% ARR
- low price set
- hardwood rotation = 50 years
- white pine rotation = 25 years

LEV - HDWDS	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	-1602.14	-1896.66	-2386.27
4	-1597.59	-1891.40	-2376.35
3	-1592.33	-1881.48	-2368.72
2	-1583.11	-1874.67	-2365.35
1	-1575.60	-1870.48	-2365.35

LEV - Pine	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	-1458.68	-1734.04	-2212.38
4	-1402.63	-1666.09	-2008.72
3	-1339.42	-1468.17	-1890.07
2	-1150.39	-1360.30	-1759.31
1	-1033.63	-1218.76	-1677.64

NPV - HDWDS	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	-1588.49	-1880.50	-2365.94
4	-1583.98	-1875.29	-2356.11
3	-1578.77	-1865.45	-2348.55
2	-1569.63	-1858.70	-2345.20
1	-1562.18	-1854.54	-2345.20

NPV - Pine	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	-1324.05	-1573.99	-2008.19
4	-1273.17	-1512.31	-1823.32
3	-1215.79	-1332.66	-1715.62
2	-1044.22	-1234.75	-1596.93
1	-938.23	-1106.27	-1522.80

Mixed hardwood and white pine LEVs ($/ha) and NPVs ($/ha):

- 10% ARR
- low price set
- hardwood rotation = 60 years
- white pine rotation = 30 years

LEV - HDWDS	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1611.05	-1906.73	-2396.90
4	-1609.23	-1904.62	-2392.93
3	-1607.13	-1900.65	-2389.88
2	-1603.44	-1897.93	-2388.53
1	-1600.43	-1896.25	-2388.53

LEV - Pine	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1453.27	-1728.75	-2201.88
4	-1410.59	-1677.02	-2046.83
3	-1362.47	-1526.34	-1956.50
2	-1218.57	-1444.23	-1856.95
1	-1129.68	-1336.47	-1794.78

NPV - HDWDS	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1605.76	-1900.47	-2389.03
4	-1603.95	-1898.37	-2385.07
3	-1601.85	-1894.41	-2382.03
2	-1598.17	-1891.70	-2380.68
1	-1595.18	-1890.03	-2380.68

NPV - Pine	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1369.98	-1629.68	-2075.69
4	-1329.76	-1580.91	-1929.53
3	-1284.39	-1438.87	-1844.38
2	-1148.73	-1361.46	-1750.54
1	-1064.94	-1259.88	-1691.92

Mixed hardwood and white pine LEVs ($/ha) and NPVs ($/ha):

- 10% ARR
- low price set
- hardwood rotation = 70 years
- white pine rotation = 35 years

LEV - HDWDS	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	-1614.80	-1910.98	-2401.42
4	-1614.08	-1910.14	-2399.85
3	-1613.25	-1908.57	-2398.64
2	-1611.78	-1907.49	-2398.10
1	-1610.59	-1906.82	-2398.10

LEV - Pine	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	-1467.43	-1746.66	-2221.20
4	-1436.59	-1709.28	-2109.16
3	-1401.82	-1600.40	-2043.89
2	-1297.83	-1541.06	-1971.96
1	-1233.60	-1463.19	-1927.03

NPV - HDWDS	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	-1612.76	-1908.56	-2398.38
4	-1612.04	-1907.72	-2396.81
3	-1611.20	-1906.15	-2395.60
2	-1609.74	-1905.07	-2395.06
1	-1608.55	-1904.41	-2395.06

NPV - Pine	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	-1415.21	-1684.51	-2142.16
4	-1385.47	-1648.46	-2034.11
3	-1351.94	-1543.45	-1971.16
2	-1251.65	-1486.22	-1901.79
1	-1189.70	-1411.13	-1858.46

Mixed hardwood and white pine LEVs ($/ha) and NPVs ($/ha):

- 10% ARR
- low price set
- hardwood rotation = 80 years
- white pine rotation = 40 years

LEV - HDWDS	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1616.34	-1912.72	-2403.29
4	-1616.06	-1912.39	-2402.67
3	-1615.73	-1911.77	-2402.19
2	-1615.15	-1911.35	-2401.98
1	-1614.68	-1911.08	-2401.98

LEV - Pine	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1485.39	-1768.88	-2246.70
4	-1463.83	-1742.75	-2168.40
3	-1439.53	-1666.65	-2122.78
2	-1366.85	-1625.18	-2072.50
1	-1321.96	-1570.76	-2041.10

NPV - HDWDS	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1615.55	-1911.79	-2402.12
4	-1615.27	-1911.46	-2401.50
3	-1614.94	-1910.84	-2401.02
2	-1614.36	-1910.41	-2400.81
1	-1613.89	-1910.15	-2400.81

NPV - Pine	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1452.57	-1729.79	-2197.06
4	-1431.49	-1704.24	-2120.48
3	-1407.72	-1629.83	-2075.87
2	-1336.65	-1589.27	-2026.71
1	-1292.75	-1536.05	-1996.00

Mixed hardwood and white pine LEVs ($/ha) and NPVs ($/ha):

- 3.5% ARR
- high price set
- hardwood rotation = 40 years
- white pine rotation = 20 years

LEV - HDWDS	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	949.48	1044.85	923.25
4	1441.57	1613.73	2060.57
3	2010.45	2751.05	2895.75
2	3070.73	3497.15	3265.24
1	3893.88	3955.72	3265.24

LEV - Pine	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1117.93	-1280.02	-1791.37
4	-643.84	-705.29	-189.78
3	-109.19	847.71	788.07
2	1370.51	1736.69	1865.77
1	2332.79	2903.26	2538.87

NPV - HDWDS	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	709.67	780.95	690.06
4	1077.47	1206.15	1540.13
3	1502.67	2056.21	2164.36
2	2295.15	2613.87	2440.53
1	2910.39	2956.61	2440.53

NPV - Pine	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-556.10	-636.73	-891.09
4	-320.27	-350.83	-94.40
3	-54.31	421.68	392.01
2	681.74	863.89	928.10
1	1160.41	1444.18	1262.92

Mixed hardwood and white pine LEVs ($/ha) and NPVs ($/ha):

- 3.5% ARR
- high price set
- hardwood rotation = 50 years
- white pine rotation = 25 years

LEV - HDWDS	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	159.28	136.05	-101.89
4	497.24	526.76	679.22
3	887.95	1307.86	1252.81
2	1616.14	1820.28	1506.58
1	2181.48	2135.22	1506.58

LEV - Pine	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-602.45	-665.46	-1013.36
4	-109.78	-68.21	650.99
3	445.82	1545.65	1667.15
2	1983.50	2469.46	2787.08
1	2983.49	3681.73	3486.56

NPV - HDWDS	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	130.76	111.69	-83.64
4	408.21	432.44	557.60
3	728.96	1073.69	1028.49
2	1326.77	1494.36	1236.82
1	1790.88	1752.91	1236.82

NPV - Pine	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-347.52	-383.87	-584.56
4	-63.33	-39.35	375.53
3	257.17	891.61	961.70
2	1144.19	1424.51	1607.74
1	1721.03	2123.82	2011.23

Mixed hardwood and white pine LEVs ($/ha) and NPVs ($/ha):

- 3.5% ARR
- high price set
- hardwood rotation = 60 years
- white pine rotation = 30 years

LEV - HDWDS	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-380.55	-485.16	-804.57
4	-145.53	-213.46	-261.39
3	126.17	329.73	137.50
2	632.56	686.07	313.97
1	1025.70	905.08	313.97

LEV - Pine	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-402.58	-429.90	-706.32
4	70.75	143.91	892.69
3	604.55	1694.41	1868.97
2	2081.86	2581.96	2944.93
1	3042.59	3746.65	3616.95

NPV - HDWDS	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-332.25	-423.58	-702.45
4	-127.06	-186.36	-228.21
3	110.16	287.88	120.04
2	552.27	598.99	274.11
1	895.51	790.20	274.11

NPV - Pine	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-259.15	-276.73	-454.67
4	45.54	92.64	574.65
3	389.16	1090.73	1203.09
2	1340.14	1662.06	1895.72
1	1958.58	2411.80	2328.31

Mixed hardwood and white pine LEVs ($/ha) and NPVs ($/ha):

- 3.5% ARR
- high price set
- hardwood rotation = 70 years
- white pine rotation = 35 years

LEV - HDWDS	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-753.54	-914.52	-1291.05
4	-588.68	-723.94	-910.03
3	-398.09	-342.92	-630.24
2	-42.89	-92.96	-506.45
1	232.88	60.67	-506.45

LEV - Pine	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-365.61	-389.76	-642.77
4	70.72	139.19	831.24
3	562.78	1568.48	1731.18
2	1924.60	2386.63	2723.03
1	2810.22	3460.27	3342.51

NPV - HDWDS	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-685.73	-832.23	-1174.88
4	-535.71	-658.79	-828.14
3	-362.27	-312.06	-573.52
2	-39.03	-84.59	-460.88
1	211.93	55.21	-460.88

NPV - Pine	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-255.93	-272.84	-449.95
4	49.50	97.44	581.89
3	393.96	1097.97	1211.87
2	1347.26	1670.70	1906.18
1	1967.22	2422.27	2339.84

Mixed hardwood and white pine LEVs ($/ha) and NPVs ($/ha):

- 3.5% ARR
- high price set
- hardwood rotation = 80 years
- white pine rotation = 40 years

LEV - HDWDS	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1013.92	-1214.33	-1631.11
4	-897.61	-1079.86	-1362.28
3	-763.14	-811.03	-1164.87
2	-512.52	-634.67	-1077.53
1	-317.95	-526.28	-1077.53

LEV - Pine	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-411.15	-448.36	-703.01
4	-18.44	27.72	623.66
3	424.44	1314.14	1433.65
2	1650.14	2050.52	2326.36
1	2447.24	3016.84	2883.93

NPV - HDWDS	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-949.24	-1136.87	-1527.06
4	-840.35	-1010.97	-1275.38
3	-714.46	-759.29	-1090.56
2	-479.82	-594.18	-1008.79
1	-297.66	-492.71	-1008.79

NPV - Pine	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-307.31	-335.12	-525.45
4	-13.78	20.72	466.14
3	317.24	982.22	1071.55
2	1233.36	1532.62	1738.79
1	1829.14	2254.87	2155.53

Mixed hardwood and white pine LEVs ($/ha) and NPVs ($/ha):

- 5% ARR
- high price set
- hardwood rotation = 40 years
- white pine rotation = 20 years

LEV - HDWDS	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-366.39	-470.91	-786.39
4	-125.30	-192.19	-229.16
3	153.42	365.04	180.03
2	672.90	730.58	361.06
1	1076.20	955.26	361.06

LEV - Pine	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1288.92	-1504.96	-2008.12
4	-1005.10	-1160.88	-1049.29
3	-685.01	-231.14	-463.87
2	200.84	301.07	181.32
1	776.94	999.47	584.29

NPV - HDWDS	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-314.35	-404.02	-674.68
4	-107.50	-164.89	-196.61
3	131.63	313.18	154.45
2	577.32	626.81	309.77
1	923.33	819.57	309.77

NPV - Pine	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-803.14	-937.76	-1251.28
4	-626.29	-723.36	-653.82
3	-426.84	-144.03	-289.04
2	125.15	187.60	112.98
1	484.12	622.78	364.08

Mixed hardwood and white pine LEVs ($/ha) and NPVs ($/ha):

- 5% ARR
- high price set
- hardwood rotation = 50 years
- white pine rotation = 25 years

LEV - HDWDS	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-847.85	-1024.66	-1412.02
4	-699.81	-853.52	-1069.88
3	-528.68	-511.38	-818.64
2	-209.71	-286.93	-707.48
1	37.91	-148.98	-707.48

LEV - Pine	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1008.27	-1171.40	-1582.47
4	-726.83	-830.20	-631.69
3	-409.43	91.74	-51.19
2	469.00	619.48	588.59
1	1040.26	1312.01	988.18

NPV - HDWDS	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-773.91	-935.31	-1288.89
4	-638.79	-779.09	-976.58
3	-482.57	-466.79	-747.25
2	-191.43	-261.91	-645.79
1	34.61	-135.99	-645.79

NPV - Pine	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-710.52	-825.48	-1115.16
4	-512.19	-585.04	-445.15
3	-288.52	64.65	-36.07
2	330.50	436.55	414.78
1	733.07	924.57	696.37

Mixed hardwood and white pine LEVs ($/ha) and NPVs ($/ha):

- 5% ARR
- high price set
- hardwood rotation = 60 years
- white pine rotation = 30 years

LEV - HDWDS	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1146.60	-1368.46	-1801.39
4	-1055.17	-1262.75	-1590.06
3	-949.46	-1051.43	-1434.87
2	-752.45	-912.79	-1366.22
1	-599.50	-827.59	-1366.22

LEV - Pine	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-926.98	-1077.09	-1454.64
4	-669.54	-764.99	-584.94
3	-379.21	78.32	-53.95
2	424.29	561.05	531.27
1	946.83	1194.52	896.78

NPV - HDWDS	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1085.22	-1295.20	-1704.95
4	-998.68	-1195.15	-1504.93
3	-898.63	-995.14	-1358.06
2	-712.17	-863.93	-1293.08
1	-567.41	-783.28	-1293.08

NPV - Pine	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-712.50	-827.87	-1118.07
4	-514.62	-587.99	-449.60
3	-291.47	60.20	-41.47
2	326.12	431.24	408.34
1	727.76	918.14	689.28

Mixed hardwood and white pine LEVs ($/ha) and NPVs ($/ha):

- 5% ARR
- high price set
- hardwood rotation = 70 years
- white pine rotation = 35 years

LEV - HDWDS	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1332.43	-1582.37	-2043.99
4	-1275.77	-1516.87	-1913.05
3	-1210.28	-1385.93	-1816.89
2	-1088.20	-1300.03	-1774.35
1	-993.43	-1247.23	-1774.35

LEV - Pine	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-940.25	-1096.03	-1468.49
4	-714.78	-822.70	-706.82
3	-460.52	-84.13	-241.78
2	243.18	338.64	270.74
1	700.82	893.42	590.85

NPV - HDWDS	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1288.64	-1530.36	-1976.81
4	-1233.84	-1467.02	-1850.17
3	-1170.50	-1340.38	-1757.18
2	-1052.44	-1257.30	-1716.03
1	-960.78	-1206.24	-1716.03

NPV - Pine	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-769.79	-897.33	-1202.26
4	-585.20	-673.55	-578.68
3	-377.03	-68.88	-197.95
2	199.10	277.25	221.66
1	573.77	731.46	483.74

Mixed hardwood and white pine LEVs ($/ha) and NPVs ($/ha):

- 5% ARR
- high price set
- hardwood rotation = 80 years
- white pine rotation = 40 years

LEV - HDWDS	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1448.26	-1715.73	-2195.38
4	-1413.10	-1675.09	-2114.14
3	-1372.47	-1593.85	-2054.48
2	-1296.73	-1534.19	-2028.09
1	-1237.92	-1507.79	-2028.09

LEV - Pine	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-995.32	-1164.79	-1545.46
4	-802.91	-931.54	-895.46
3	-585.93	-301.26	-498.61
2	14.60	59.52	-61.23
1	405.14	532.97	211.94

NPV - HDWDS	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1419.03	-1681.11	-2151.09
4	-1384.59	-1641.29	-2071.48
3	-1344.77	-1561.69	-2013.03
2	-1270.56	-1503.23	-1987.17
1	-1212.95	-1477.37	-1987.17

NPV - Pine	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-853.94	-999.34	-1325.93
4	-688.86	-799.22	-768.26
3	-502.70	-258.47	-427.78
2	12.53	51.07	-52.53
1	347.59	457.26	181.84

Mixed hardwood and white pine LEVs ($/ha) and NPVs ($/ha):

- 7.5% ARR
- high price set
- hardwood rotation = 40 years
- white pine rotation = 20 years

LEV - HDWDS	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1176.30	-1404.78	-1835.23
4	-1090.86	-1306.01	-1637.77
3	-992.09	-1108.54	-1492.76
2	-808.00	-979.00	-1428.61
1	-665.09	-899.39	-1428.61

LEV - Pine	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1409.79	-1665.34	-2158.81
4	-1265.31	-1490.19	-1670.72
3	-1102.37	-1016.91	-1372.72
2	-651.43	-745.99	-1044.29
1	-358.18	-390.48	-839.16

NPV - HDWDS	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1111.11	-1326.93	-1733.52
4	-1030.41	-1233.63	-1547.00
3	-937.11	-1047.11	-1410.03
2	-763.22	-924.75	-1349.44
1	-628.23	-849.54	-1349.44

NPV - Pine	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1077.91	-1273.30	-1650.60
4	-967.44	-1139.38	-1277.41
3	-842.86	-777.52	-1049.56
2	-498.08	-570.38	-798.45
1	-273.86	-298.56	-641.61

Mixed hardwood and white pine LEVs ($/ha) and NPVs ($/ha):

- 7.5% ARR
- high price set
- hardwood rotation = 50 years
- white pine rotation = 25 years

LEV - HDWDS	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1398.85	-1660.75	-2124.95
4	-1356.03	-1611.25	-2025.99
3	-1306.53	-1512.29	-1953.32
2	-1214.28	-1447.37	-1921.17
1	-1142.65	-1407.47	-1921.17

LEV - Pine	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1291.06	-1525.14	-1976.89
4	-1159.32	-1365.44	-1531.86
3	-1010.76	-933.91	-1260.15
2	-599.60	-686.90	-960.69
1	-332.22	-362.75	-773.65

NPV - HDWDS	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1361.24	-1616.09	-2067.81
4	-1319.57	-1567.92	-1971.52
3	-1271.40	-1471.62	-1900.80
2	-1181.63	-1408.45	-1869.51
1	-1111.93	-1369.62	-1869.51

NPV - Pine	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1079.35	-1275.05	-1652.72
4	-969.22	-1141.54	-1280.66
3	-845.02	-780.77	-1053.51
2	-501.28	-574.26	-803.16
1	-277.74	-303.26	-646.79

Mixed hardwood and white pine LEVs ($/ha) and NPVs ($/ha):

- 7.5% ARR
- high price set
- hardwood rotation = 60 years
- white pine rotation = 30 years

LEV - HDWDS	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1512.81	-1791.88	-2273.68
4	-1491.44	-1767.18	-2224.29
3	-1466.74	-1717.79	-2188.03
2	-1420.70	-1685.39	-2171.98
1	-1384.96	-1665.48	-2171.98

LEV - Pine	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1279.15	-1512.95	-1954.91
4	-1168.87	-1379.26	-1582.37
3	-1044.50	-1018.01	-1354.91
2	-700.31	-811.23	-1104.23
1	-476.47	-539.87	-947.65

NPV - HDWDS	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1493.08	-1768.51	-2244.02
4	-1471.99	-1744.12	-2195.28
3	-1447.61	-1695.38	-2159.48
2	-1402.16	-1663.41	-2143.65
1	-1366.89	-1643.75	-2143.65

NPV - Pine	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1133.04	-1340.14	-1731.62
4	-1035.36	-1221.72	-1401.63
3	-925.20	-901.73	-1200.15
2	-620.32	-718.57	-978.10
1	-422.05	-478.21	-839.41

Mixed hardwood and white pine LEVs ($/ha) and NPVs ($/ha):

- 7.5% ARR
- high price set
- hardwood rotation = 70 years
- white pine rotation = 35 years

LEV - HDWDS	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1570.53	-1858.32	-2349.12
4	-1559.91	-1846.04	-2324.57
3	-1547.63	-1821.49	-2306.54
2	-1524.75	-1805.39	-2298.57
1	-1506.98	-1795.49	-2298.57

LEV - Pine	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1309.09	-1550.67	-1996.10
4	-1221.08	-1443.98	-1698.77
3	-1121.83	-1155.67	-1517.24
2	-847.13	-990.64	-1317.17
1	-668.49	-774.07	-1192.22

NPV - HDWDS	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1560.59	-1846.55	-2334.25
4	-1550.03	-1834.35	-2309.86
3	-1537.83	-1809.96	-2291.94
2	-1515.09	-1793.96	-2284.02
1	-1497.44	-1784.13	-2284.02

NPV - Pine	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1204.94	-1427.30	-1837.29
4	-1123.93	-1329.09	-1563.62
3	-1032.57	-1063.72	-1396.53
2	-779.73	-911.82	-1212.38
1	-615.30	-712.49	-1097.36

Mixed hardwood and white pine LEVs ($/ha) and NPVs ($/ha):

- 7.5% ARR
- high price set
- hardwood rotation = 80 years
- white pine rotation = 40 years

LEV - HDWDS	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1599.53	-1891.70	-2387.05
4	-1594.27	-1885.62	-2374.90
3	-1588.19	-1873.47	-2365.97
2	-1576.86	-1865.49	-2362.03
1	-1568.06	-1860.59	-2362.03

LEV - Pine	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1351.44	-1602.94	-2056.49
4	-1283.26	-1520.28	-1826.15
3	-1206.36	-1296.93	-1685.52
2	-993.55	-1169.08	-1530.52
1	-855.16	-1001.30	-1433.72

NPV - HDWDS	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1594.61	-1885.89	-2379.72
4	-1589.37	-1879.83	-2367.61
3	-1583.31	-1867.71	-2358.71
2	-1572.01	-1859.76	-2354.77
1	-1563.24	-1854.88	-2354.77

NPV - Pine	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1276.54	-1514.10	-1942.52
4	-1212.14	-1436.03	-1724.95
3	-1139.51	-1225.05	-1592.11
2	-938.49	-1104.29	-1445.70
1	-807.77	-945.81	-1354.26

Mixed hardwood and white pine LEVs ($/ha) and NPVs ($/ha):

- 10% ARR
- high price set
- hardwood rotation = 40 years
- white pine rotation = 20 years

LEV - HDWDS	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1443.10	-1713.42	-2177.13
4	-1410.20	-1675.39	-2101.09
3	-1372.17	-1599.34	-2045.24
2	-1301.27	-1549.46	-2020.54
1	-1246.24	-1518.80	-2020.54

LEV - Pine	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1459.63	-1732.91	-2218.31
4	-1377.70	-1633.59	-1941.54
3	-1285.30	-1365.21	-1772.55
2	-1029.59	-1211.58	-1586.31
1	-863.29	-1009.99	-1469.99

NPV - HDWDS	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1411.22	-1675.56	-2129.03
4	-1379.04	-1638.37	-2054.66
3	-1341.85	-1564.00	-2000.05
2	-1272.52	-1515.22	-1975.90
1	-1218.70	-1485.24	-1975.90

NPV - Pine	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1242.66	-1475.33	-1888.58
4	-1172.91	-1390.77	-1652.94
3	-1094.25	-1162.28	-1509.07
2	-876.55	-1031.49	-1350.52
1	-734.97	-859.86	-1251.48

Mixed hardwood and white pine LEVs ($/ha) and NPVs ($/ha):

- 10% ARR
- high price set
- hardwood rotation = 50 years
- white pine rotation = 25 years

LEV - HDWDS	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1545.97	-1831.73	-2311.21
4	-1532.66	-1816.33	-2280.44
3	-1517.27	-1785.56	-2257.84
2	-1486.50	-1765.38	-2247.85
1	-1466.31	-1752.97	-2247.85

LEV - Pine	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1405.89	-1670.05	-2134.80
4	-1337.60	-1587.26	-1904.10
3	-1260.59	-1363.55	-1763.24
2	-1047.44	-1235.50	-1608.00
1	-908.83	-1067.46	-1511.05

NPV - HDWDS	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1532.80	-1816.12	-2291.52
4	-1519.60	-1800.86	-2261.01
3	-1504.34	-1770.35	-2238.61
2	-1473.83	-1750.34	-2228.70
1	-1453.82	-1738.04	-2228.70

NPV - Pine	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1276.14	-1515.91	-1937.77
4	-1214.15	-1440.76	-1728.36
3	-1144.24	-1237.70	-1600.50
2	-950.77	-1121.47	-1459.59
1	-824.95	-968.93	-1371.58

Mixed hardwood and white pine LEVs ($/ha) and NPVs ($/ha):

- 10% ARR
- high price set
- hardwood rotation = 60 years
- white pine rotation = 30 years

LEV - HDWDS	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1588.58	-1880.75	-2366.87
4	-1583.25	-1874.59	-2354.55
3	-1577.09	-1862.28	-2345.51
2	-1565.62	-1854.20	-2341.52
1	-1556.71	-1849.24	-2341.52

LEV - Pine	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1413.08	-1680.03	-2142.82
4	-1361.09	-1617.01	-1967.19
3	-1302.46	-1446.70	-1859.95
2	-1140.19	-1349.21	-1741.77
1	-1034.67	-1221.28	-1667.95

NPV - HDWDS	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1583.36	-1874.57	-2359.09
4	-1578.05	-1868.43	-2346.82
3	-1571.91	-1856.16	-2337.81
2	-1560.48	-1848.11	-2333.83
1	-1551.59	-1843.17	-2333.83

NPV - Pine	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1332.10	-1583.75	-2020.02
4	-1283.09	-1524.34	-1854.45
3	-1227.82	-1363.79	-1753.36
2	-1074.85	-1271.89	-1641.95
1	-975.37	-1151.29	-1572.37

Mixed hardwood and white pine LEVs ($/ha) and NPVs ($/ha):

- 10% ARR
- high price set
- hardwood rotation = 70 years
- white pine rotation = 35 years

LEV - HDWDS	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	-1605.89	-1900.67	-2389.50
4	-1603.77	-1898.22	-2384.62
3	-1601.33	-1893.34	-2381.03
2	-1596.77	-1890.13	-2379.44
1	-1593.24	-1888.16	-2379.44

LEV - Pine	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	-1438.39	-1711.46	-2178.53
4	-1400.82	-1665.91	-2051.61
3	-1358.45	-1542.85	-1974.12
2	-1241.20	-1472.40	-1888.72
1	-1164.94	-1379.96	-1835.38

NPV - HDWDS	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	-1603.85	-1898.26	-2386.48
4	-1601.74	-1895.82	-2381.60
3	-1599.30	-1890.94	-2378.02
2	-1594.75	-1887.74	-2376.43
1	-1591.22	-1885.77	-2376.43

NPV - Pine	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	-1387.21	-1650.56	-2101.00
4	-1350.97	-1606.63	-1978.61
3	-1310.11	-1487.95	-1903.87
2	-1197.03	-1420.01	-1821.51
1	-1123.49	-1330.86	-1770.07

Mixed hardwood and white pine LEVs ($/ha) and NPVs ($/ha):

- 10% ARR
- high price set
- hardwood rotation = 80 years
- white pine rotation = 40 years

LEV - HDWDS	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1612.83	-1908.66	-2398.59
4	-1611.99	-1907.69	-2396.66
3	-1611.03	-1905.77	-2395.25
2	-1609.23	-1904.50	-2394.62
1	-1607.84	-1903.73	-2394.62

LEV - Pine	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1465.09	-1744.27	-2216.88
4	-1438.83	-1712.44	-2128.17
3	-1409.22	-1626.43	-2074.01
2	-1327.27	-1577.19	-2014.33
1	-1273.97	-1512.58	-1977.05

NPV - HDWDS	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1612.04	-1907.73	-2397.42
4	-1611.21	-1906.76	-2395.49
3	-1610.24	-1904.84	-2394.08
2	-1608.45	-1903.57	-2393.45
1	-1607.05	-1902.80	-2393.45

NPV - Pine	**Site preparation intensity**		
Site class	*Low*	*Medium*	*High*
5	-1432.72	-1705.73	-2167.89
4	-1407.04	-1674.60	-2081.15
3	-1378.08	-1590.49	-2028.19
2	-1297.94	-1542.34	-1969.82
1	-1245.82	-1479.16	-1933.36

Appendix B – Mixed hardwood and white pine incentive values

Mixed hardwood incentive values for:

- 3.5% ARR
- low price set
- hardwood rotation = 60 years

HDWDS lump sum payment at planting ($/ha)

	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	1372.05	1631.40	2129.71
4	1291.77	1538.59	1954.57
3	1198.96	1363.46	1819.94
2	1036.24	1243.19	1760.38
1	903.55	1169.27	1760.38

HDWDS annual payment ($/ha/yr)

	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	48.02	57.10	74.54
4	45.21	53.85	68.41
3	41.96	47.72	63.70
2	36.27	43.51	61.61
1	31.62	40.92	61.61

HDWDS revenue incentive at harvest ($/ha)

	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	9437.09	11220.92	14648.32
4	8884.91	10582.56	13443.73
3	8246.55	9377.97	12517.74
2	7127.38	8550.74	12108.08
1	6214.73	8042.32	12108.08

HDWDS carbon subsidy ($/ton of carbon)

	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	1.37	1.42	1.61
4	1.12	1.17	1.29
3	0.91	0.90	1.05
2	0.69	0.73	0.96
1	0.53	0.64	0.96

White pine incentive values for:

- 3.5% ARR
- low price set
- white pine rotation = 30 years

Pine lump sum payment at planting ($/ha)

	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	768.42	873.41	1243.99
4	379.93	402.45	*
3	*	*	*
2	*	*	*
1	*	*	*

Pine annual payment ($/ha/yr)

	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	26.89	30.57	43.54
4	13.30	14.09	*
3	*	*	*
2	*	*	*
1	*	*	*

Pine revenue incentive at harvest ($/ha)

	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	1388.38	1578.08	2247.63
4	686.46	727.15	*
3	*	*	*
2	*	*	*
1	*	*	*

Pine carbon subsidy ($/ton of carbon)

	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	1.73	1.62	1.91
4	0.69	0.61	*
3	*	*	*
2	*	*	*
1	*	*	*

Mixed hardwood incentive values for:

- 5% ARR
- low price set
- hardwood rotation = 60 years

HDWDS lump sum payment at planting ($/ha)

	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	1532.35	1814.41	2316.93
4	1501.11	1778.30	2248.79
3	1465.01	1710.16	2196.42
2	1401.70	1663.37	2173.24
1	1350.08	1634.61	2173.24

HDWDS annual payment ($/ha/yr)

	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	76.62	90.72	115.85
4	75.06	88.91	112.44
3	73.25	85.51	109.82
2	70.09	83.17	108.66
1	67.50	81.73	108.66

HDWDS revenue incentive at harvest ($/ha)

	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	27090.65	32077.21	40961.42
4	26538.47	31438.86	39756.83
3	25900.11	30234.27	38830.85
2	24780.95	29407.04	38421.18
1	23868.29	28898.61	38421.18

HDWDS carbon subsidy ($/ton of carbon)

	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	2.45	2.54	2.82
4	2.10	2.17	2.39
3	1.79	1.82	2.03
2	1.51	1.56	1.90
1	1.27	1.43	1.90

White pine incentive values for:

- 5% ARR
- low price set
- white pine rotation = 30 years

Pine lump sum payment at planting ($/ha)

	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	1125.97	1318.31	1747.07
4	914.67	1062.16	979.31
3	676.38	316.06	532.05
2	*	*	39.10
1	*	*	*

Pine annual payment ($/ha/yr)

	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	56.30	65.92	87.35
4	45.73	53.11	48.97
3	33.82	15.80	26.60
2	*	*	1.96
1	*	*	*

Pine revenue incentive at harvest ($/ha)

	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	3740.39	4379.36	5803.68
4	3038.47	3528.43	3253.23
3	2246.89	1049.92	1767.43
2	*	*	129.90
1	*	*	*

Pine carbon subsidy ($/ton of carbon)

	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	4.13	3.99	4.36
4	2.72	2.61	1.98
3	1.66	0.64	0.89
2	*	*	0.05
1	*	*	*

Mixed hardwood incentive values for:

- 7.5% ARR
- low price set
- hardwood rotation = 60 years

HDWDS lump sum payment at planting ($/ha)

	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	1602.96	1896.10	2394.16
4	1595.66	1887.66	2378.24
3	1587.22	1871.74	2366.00
2	1572.43	1860.80	2360.58
1	1560.36	1854.08	2360.58

HDWDS annual payment ($/ha/yr)

	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	120.22	142.21	179.56
4	119.67	141.57	178.37
3	119.04	140.38	177.45
2	117.93	139.56	177.04
1	117.03	139.06	177.04

HDWDS revenue incentive at harvest ($/ha)

	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	121262.76	143438.59	181116.65
4	120710.58	142800.23	179912.06
3	120072.23	141595.64	178986.08
2	118953.06	140768.42	178576.41
1	118040.41	140259.99	178576.41

HDWDS carbon subsidy ($/ton of carbon)

	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	4.68	4.83	5.32
4	4.06	4.20	4.61
3	3.53	3.63	4.00
2	3.09	3.19	3.78
1	2.67	2.97	3.78

White pine incentive values for:

- 7.5% ARR
- low price set
- white pine rotation = 30 years

Pine lump sum payment at planting ($/ha)

	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	1364.38	1616.28	2080.18
4	1273.87	1506.55	1751.30
3	1171.80	1186.95	1559.71
2	866.56	1012.77	1348.55
1	678.01	784.20	1216.67

Pine annual payment ($/ha/yr)

	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	102.33	121.22	156.01
4	95.54	112.99	131.35
3	87.88	89.02	116.98
2	64.99	75.96	101.14
1	50.85	58.81	91.25

Pine revenue incentive at harvest ($/ha)

	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	10580.74	12534.18	16131.73
4	9878.82	11683.25	13581.28
3	9087.23	9204.74	12095.48
2	6720.11	7853.97	10457.95
1	5257.95	6081.42	9435.20

Pine carbon subsidy ($/ton of carbon)

	Site preparation intensity		
Site class	*Low*	*Medium*	*High*
5	9.42	9.20	9.77
4	7.14	6.96	6.68
3	5.42	4.53	4.91
2	3.36	3.24	3.55
1	2.17	2.07	2.91

VITA

- Jonathan Edward Aggett -

Professional Interests: Forestry: economics; harvest scheduling; linear programming; growth and yield

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Undergraduate Degree: Bachelor of Science in Forestry from the University of Stellenbosch, South Africa. 3rd year of undergraduate degree from Virginia Tech (exchange year). Graduated December 2000.

Graduate Degree: Masters Degree in Forestry Economics at Virginia Tech (2001-2003). Thesis topic: Financial analysis of converting reclaimed mined lands to forests.

Academic achievements:

- Mathematics award (top Math student) - final year of high school (1996)
- Woodwork award (top Woodwork student - practical, theory and drawings) - final year of high school (1996)
- Parel Vallei Award - award for all-round excellence throughout high school career - academic, cultural & sport (1996)
- Advanced to second round of Old Mutual Mathematics Olympiad (Nation-wide olympiad - South Africa, 1996)
- Top Forestry Student – 1st year Undergraduate (1997)
- Hans Merensky Bursary - awarded to a Forestry student, based on academic records (1998 & 1999)
- Dr. John F. Hosner Scholarship - from the Colonial Agricultural Educational Foundation, Inc. (2002/2003)\

Leadership positions:

- Deputy headboy of school - group of 16 students chosen from the senior class to lead the school i.e. maintain discipline, etc. From this group of 16 are chosen a headboy and a deputy headboy to assume leadership of this prefect-body - final year of high school (1996)
- Served as a member of the Junior Town Council of Somerset West (South Africa) (1995-1996) - organizing events for the youth of Somerset West (my home town)
- Class representative during undergraduate studies - mediator between students and lecturers with regards to academic issues (1997-2000)
- Served as a member of the Stellenbosch Forestry Student Association (SFSA) (1999) - 6 students selected by the Forestry students to represent the Forestry Faculty
- Captain of rugby team (throughout high school career)

Previous Employment:

- Worked for six weeks (December 1996 - February 1997), after graduating from high school, for a forestry company in South Africa (SAFCOL). Worked as a laborer, doing primarily: weed-control, pruning, fertilizing, planting, and a bit of map work. *Employer: Gareth Tudor-Jones.*
- Worked for four months (February - June 2001) as a volunteer on the maintenance crew for the "English Hospital" in Nazareth, Israel. Worked primarily in the carpentry. *Employer: Derek Thomson.*
- Teaching assistant for two successive years (2001/2002) for undergraduate Forest Resources Management course (FOR 4424) at Virginia Tech. This course dealt primarily with classical through current approaches to the management of private and public forests for a variety of objectives. Linear programming and harvest scheduling comprised a large part of this course. *Employer: Dr. Jay Sullivan.*